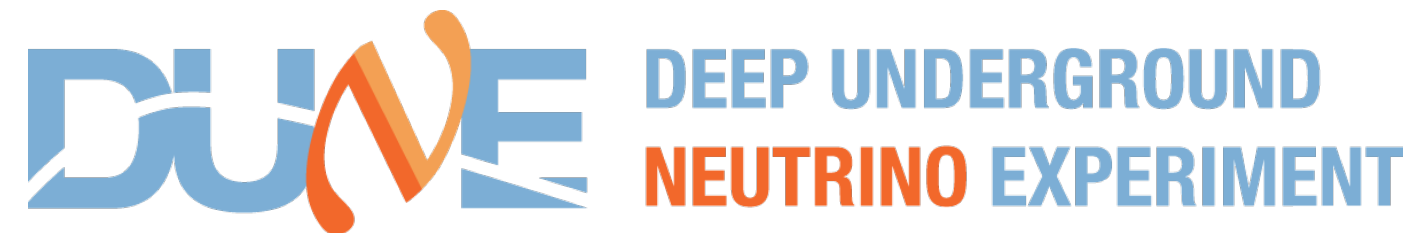# SiPM Passive and Active Ganging with Cable Variation

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(Indiana University)

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DUNE Photon Detection Workshop
Ft. Collins, Colorado

Contents

- Experimental Methods
- Analysis Methods
- Passive ganging analysis
- Look at Active ganging studies

Experimental Methods

- The electronics board holding SiPMs and related circuitry is suspended in a glass dewar

- Dewar is filled with liquid nitrogen (LN2) and placed inside a dark box

- Gore shielded twisted pairs connect the SiPMs to feed-throughs on side of dark box

- Varying cable lengths (10m, 20m, and 40m) carry signals from dark box to Argonne SiPM Signal Processor (SSP)

- For active board, SPI controls the bias voltage of each SiPM (uses ribbon feed-through)

Experimental Methods
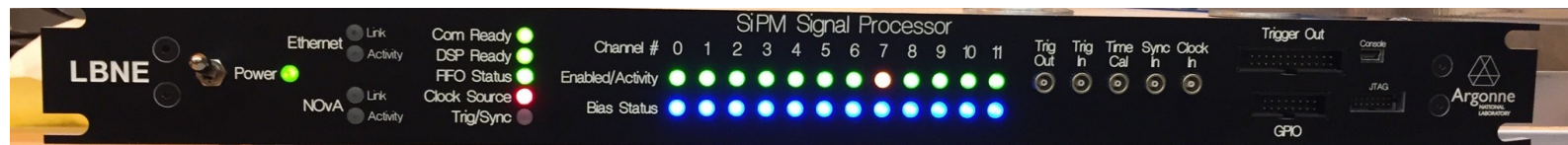
Analysis

- The SSP's peakSum variable calculates the sum of samples near peak of waveform and is used to separate waveforms by photoelectrons (PE).

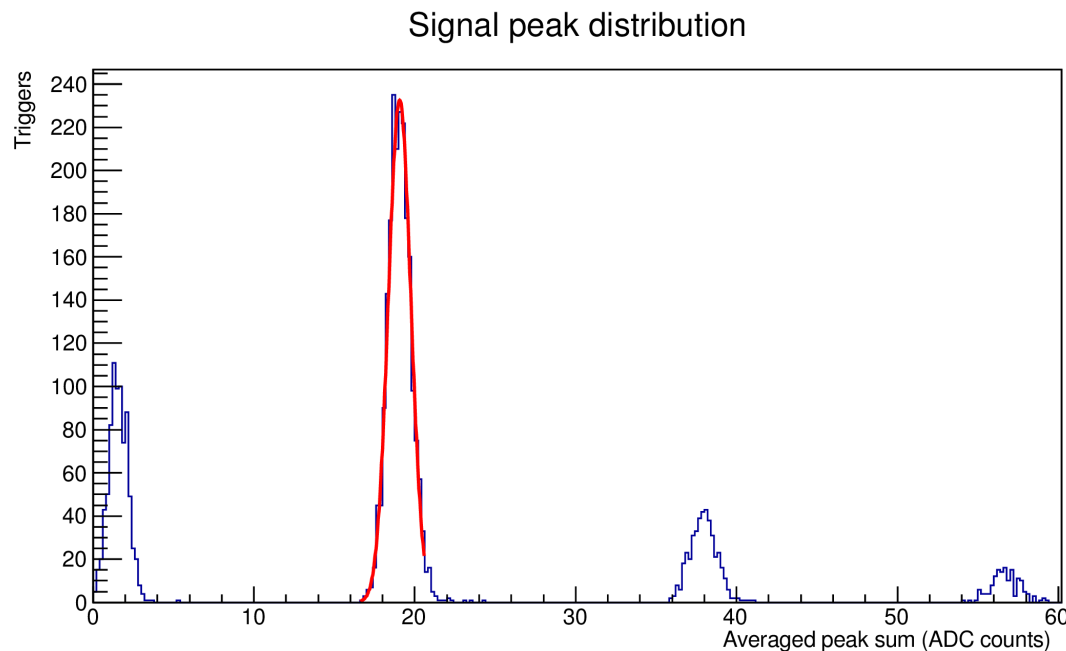- Plot this variable for all collected waveforms to see baseline triggers (0PE) and pulses (1PE, 2PE, ...)

Signal peak distribution

5
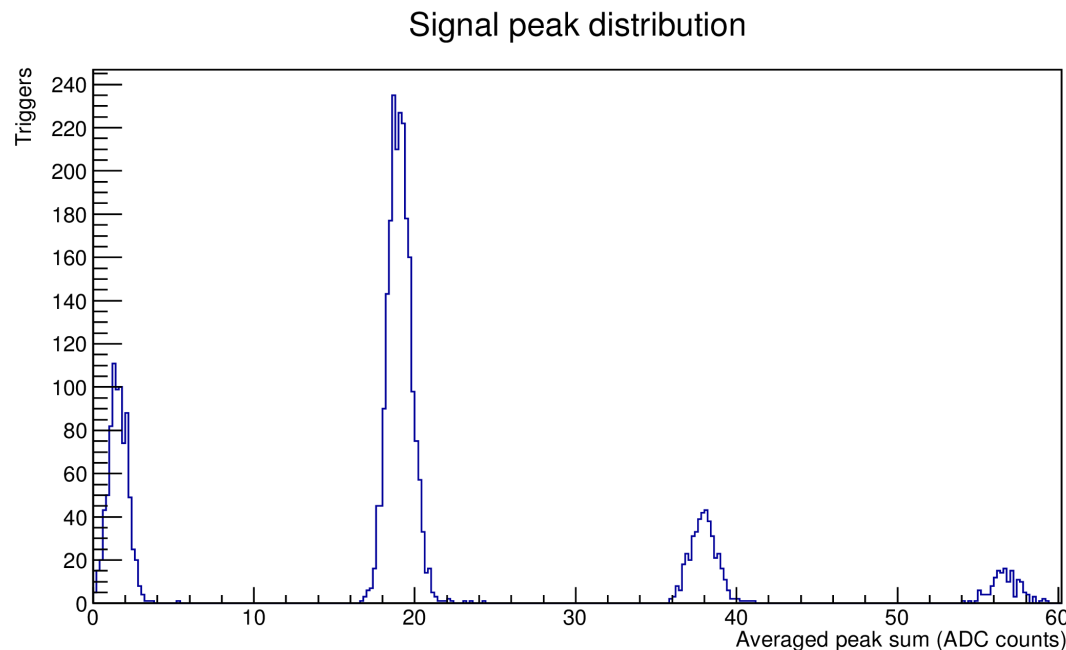
Analysis

- Find peak bin in the distribution for the desired number of PE. Fit Gaussian to region

Peak +/- 2 ADC

- Scan through waveforms again, accepting any waveform which falls within 1 sigma of the Gaussian mean

Signal peak distribution

Analysis

- Use ROOT's TProfile to average accepted waveforms and report errors on each sample

- Determine amplitude of averaged waveform by scanning across and finding the maximum 5-sample average.

- <u>ADC/PE</u>: Average of (amplitude / # of PE) for the 2 consecutive lowest PEs triggered on

Averaged 1 PE waveform
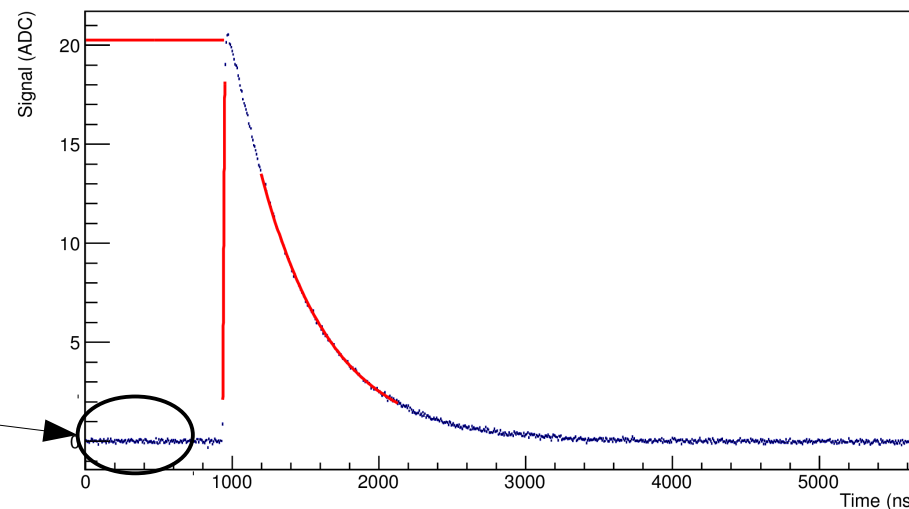
Baseline RMS calculated out here

Analysis

- Selection RMS: RMS is calculated for first 100 samples from each selected waveform (well before rising edge). Mean of this distribution is reported and characterizes the baseline.

- Rise Time: Find first sample in rising edge with at least ½ determined amplitude. Use this sample and preceding to determine a line. The time for this line to traverse 10-90% of this peak is the rise time.

- Decay Constant: Use scanning 5-bin average to find location at which falling edge crosses 70% and 10% of the determined amplitude. Fit a single exponential to this region.

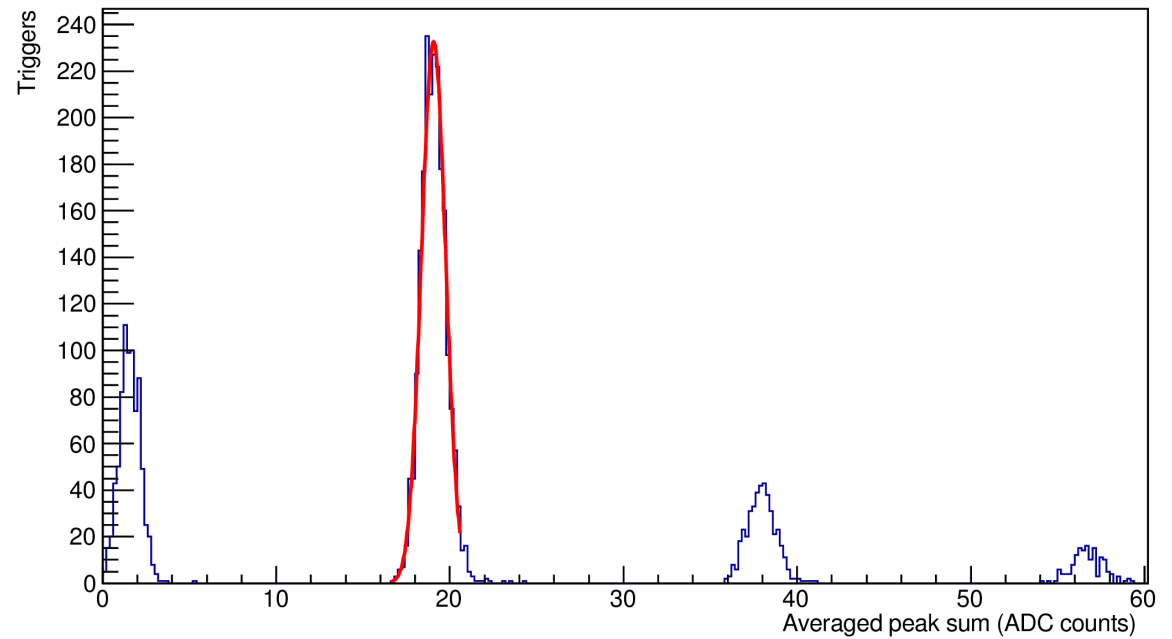# Passive Ganging Results

- Board contains 3 <u>individual</u> SiPMs, one set of <u>3 passively ganged</u> SiPMs, and one set of <u>6 passively ganged</u> SiPMs.

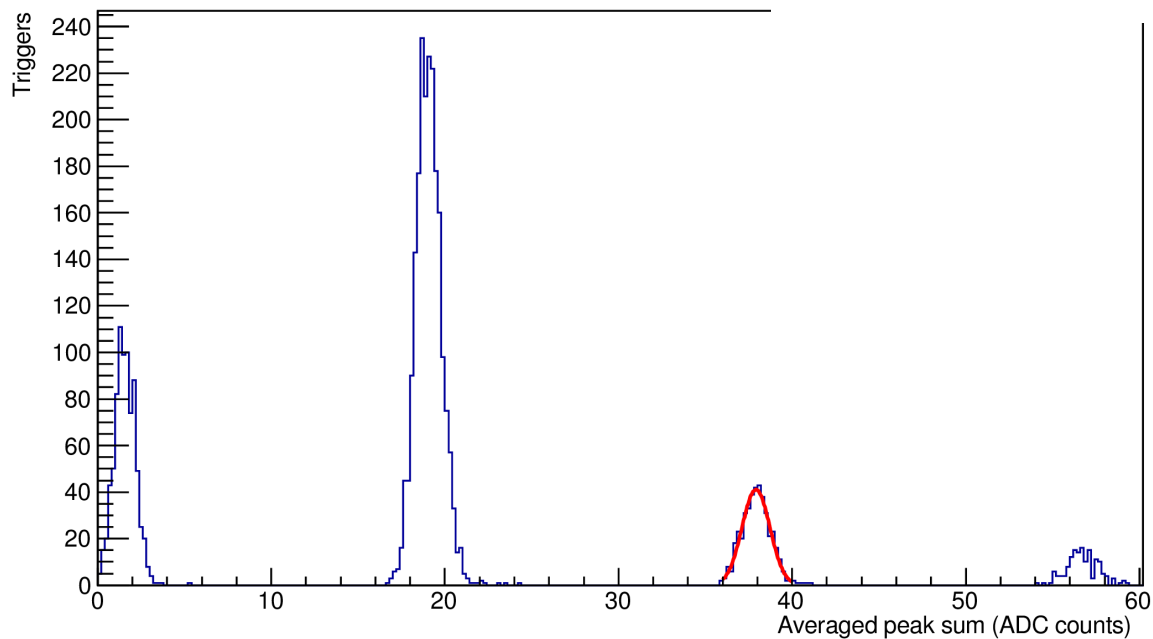 - The individual SiPMs are averaged for the final results

An individual SiPM's response data – 10m cable

1 PE
selection

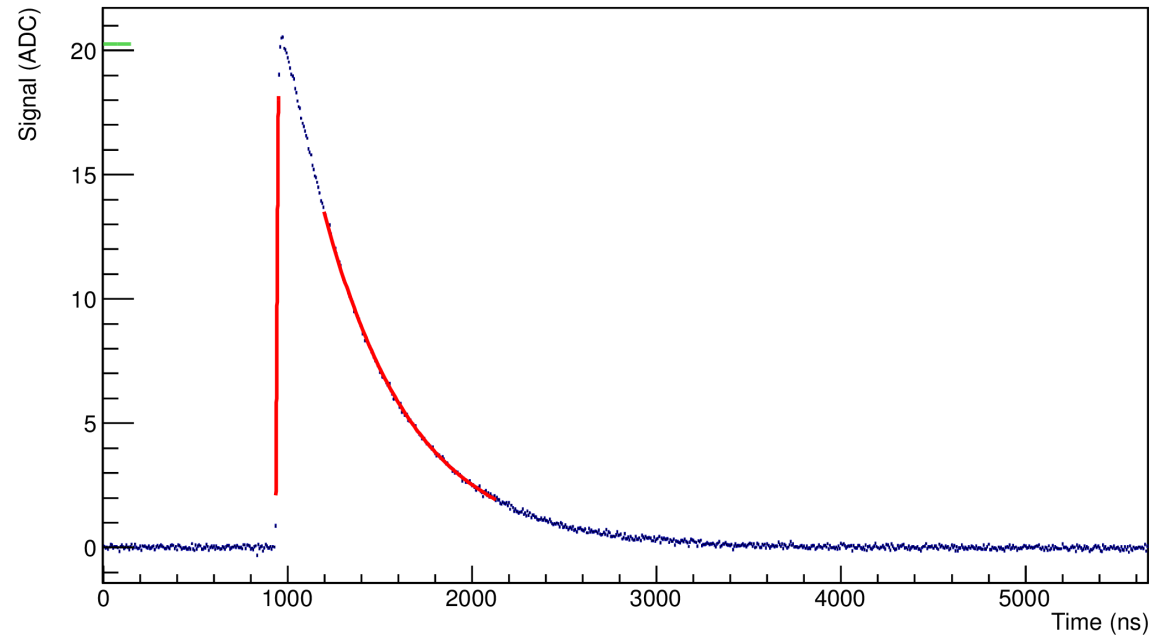Signal peak distribution

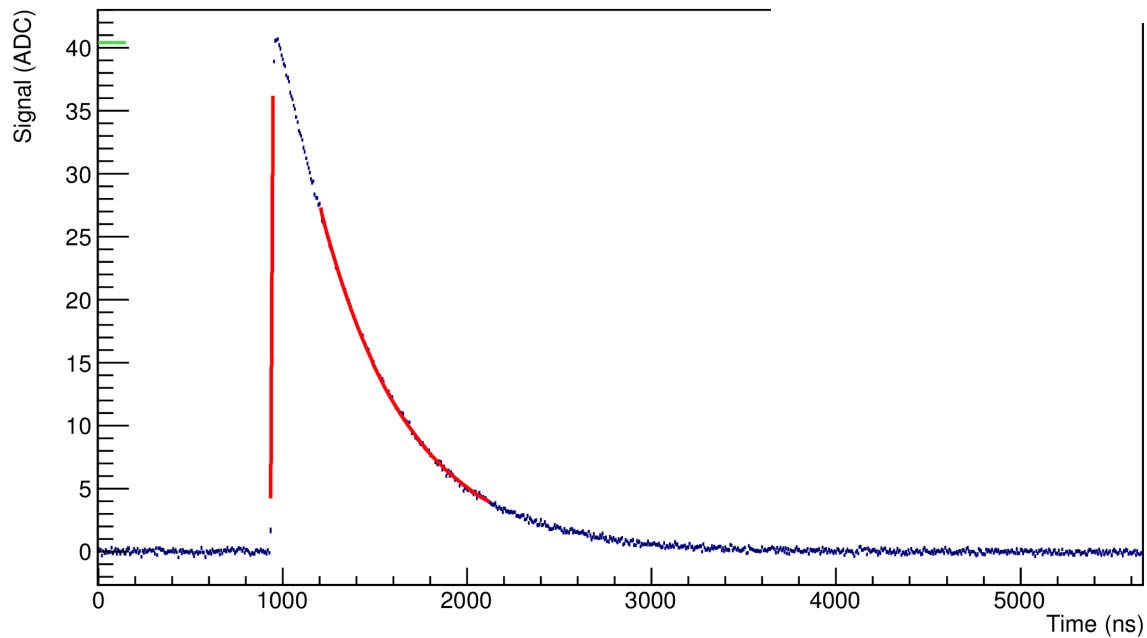2 PE
selection

Signal peak distribution

An individual SiPM's response data – 10m cable

Averaged 1 PE waveform

1 PE
selection

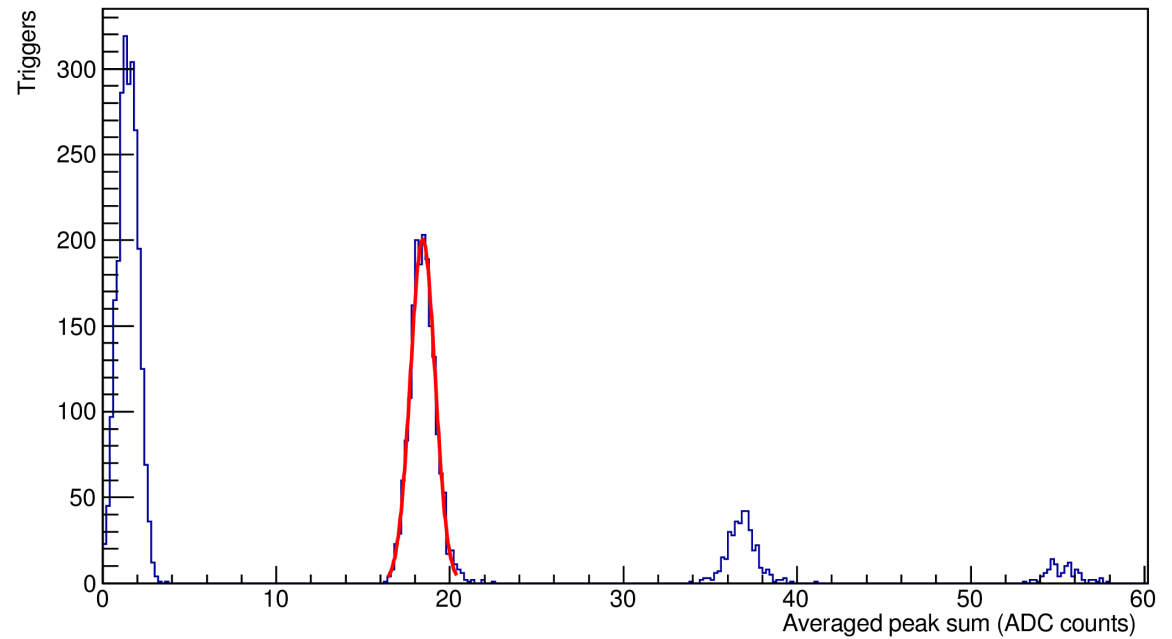Averaged 2 PE wavefo...
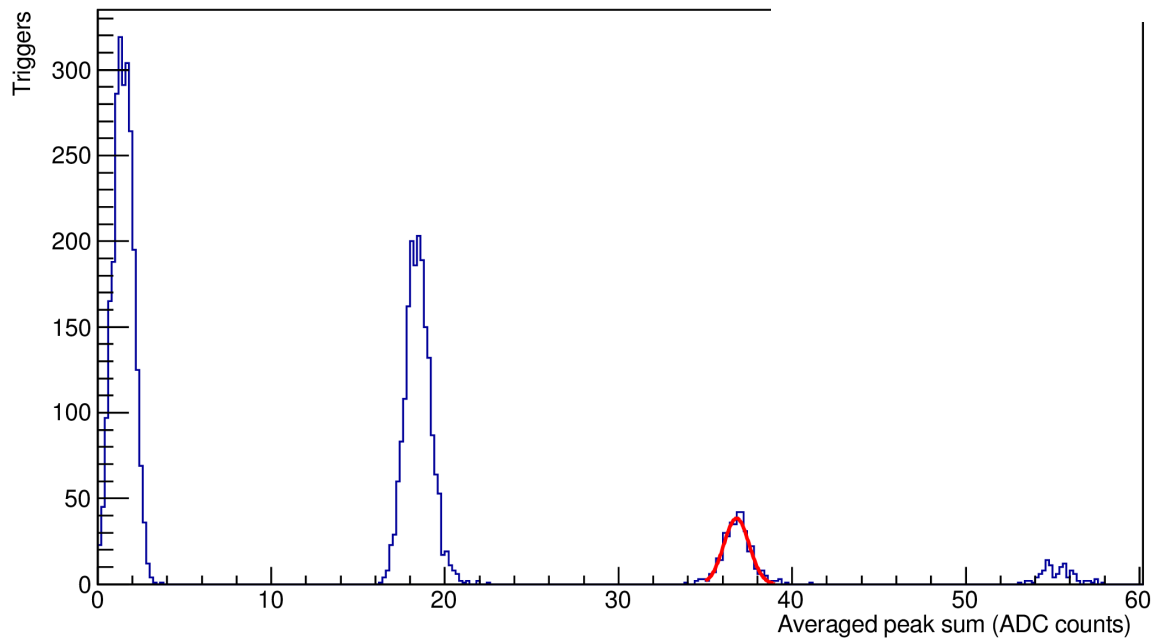
2 PE
selection

11

An individual SiPM's response data – 20m cable

Signal peak distribution
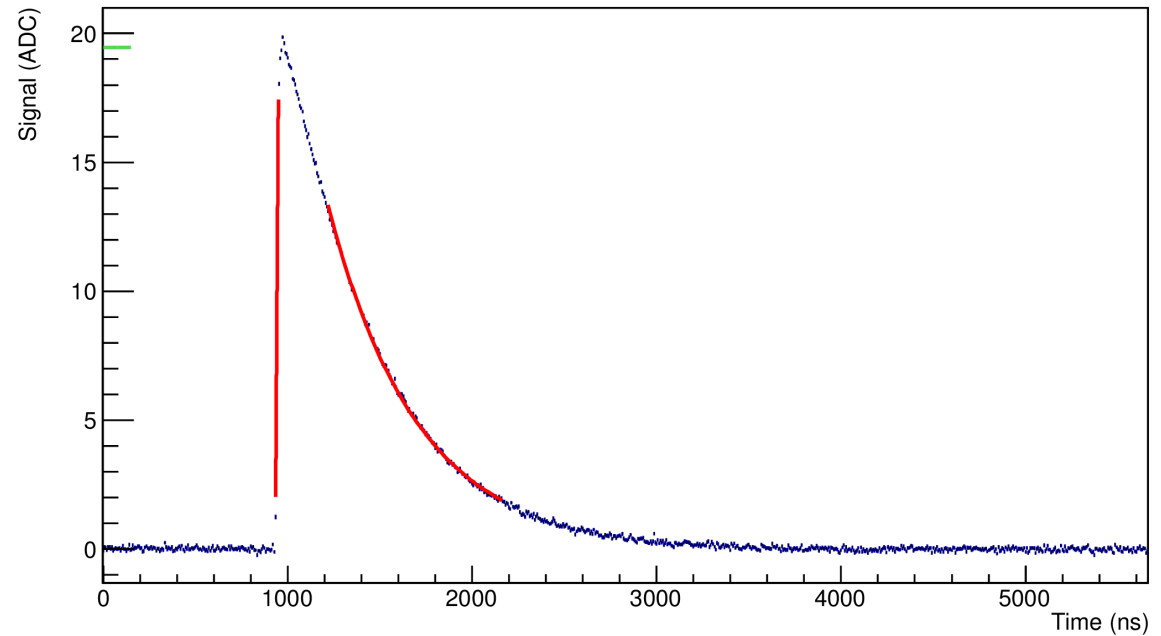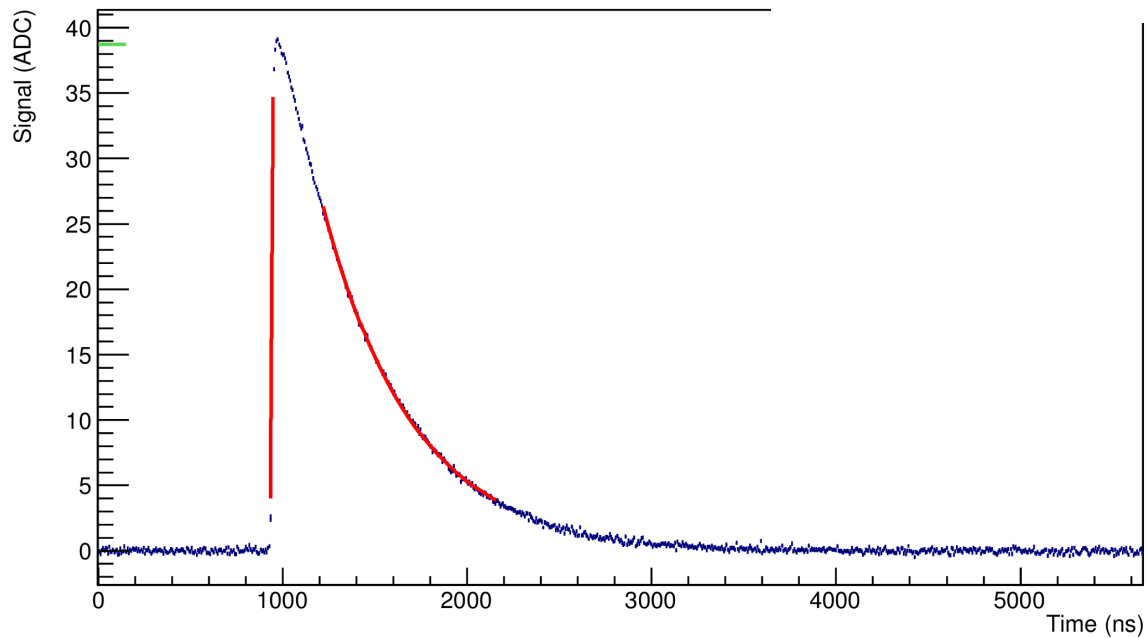
1 PE
selection

Signal peak distribution

2 PE
selection

12

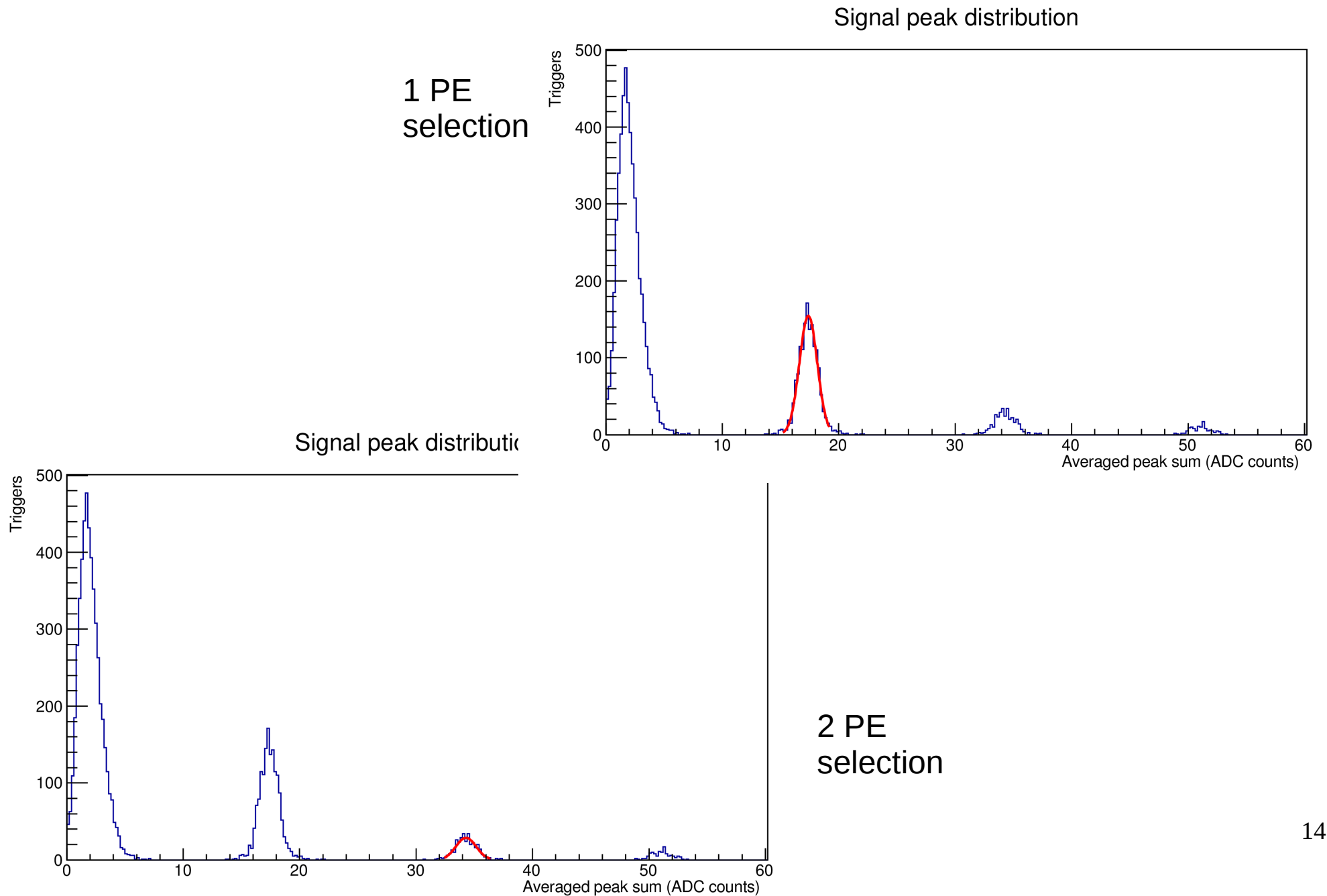# An individual SiPM's response data – 20m cable

1 PE
selection

Averaged 1 PE waveform

2 PE
selection

Averaged 2 PE wavefo

13

An individual SiPM's response data – 40m cable

Signal peak distribution

1 PE
selection

Triggers

Averaged peak sum (ADC counts)

Signal peak distribution

Triggers

2 PE
selection

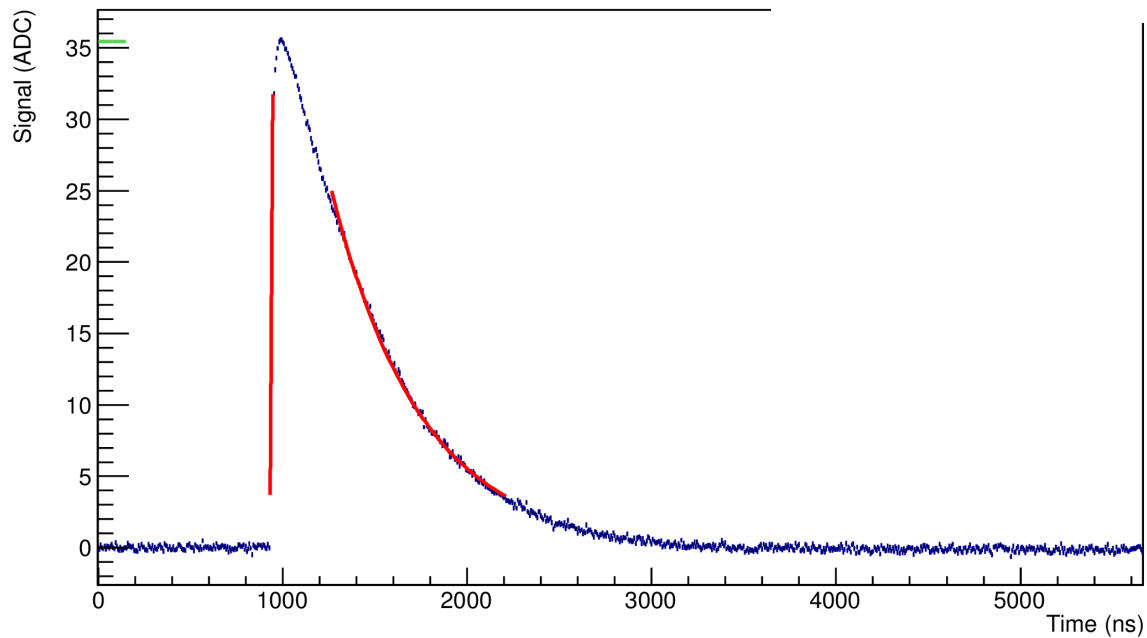Averaged peak sum (ADC counts)

14

An individual SiPM's response data – 40m cable

1 PE selection

Averaged 1 PE waveform
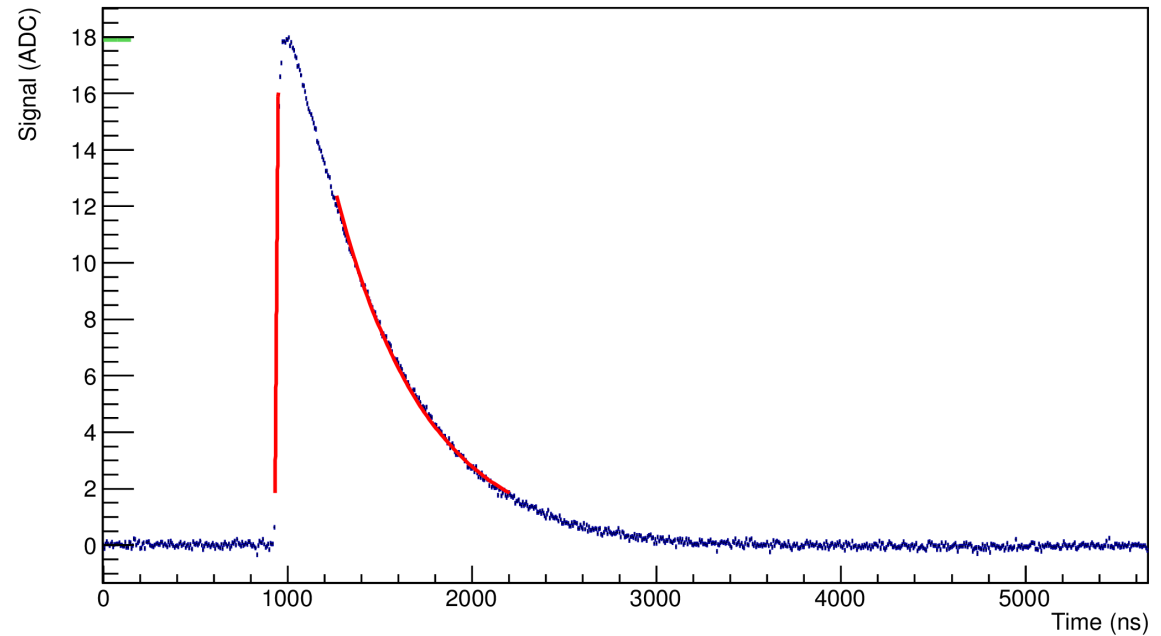
2 PE selection

Averaged 2 PE waveform

Average Individual SiPM Single PE response				
Cable Length (m)	**Baseline RMS (ADC)**	**ADC/PE**	**Rise Time (ns)**	**Decay Constant (ns)**
10	2.45 +/- .18	20.3	13.4 +/- .3	473
20	2.49 +/- .20	19.5	14.7 +/- .4	479
40	2.54 +/- .22	17.8	18.6 +/- .7	490

Gang of 3 SiPMs – 10m cable

Signal peak distribution

1 PE selection

Triggers

Averaged peak sum (ADC counts)

Signal peak distribution

2 PE selection

Triggers

Averaged peak sum (ADC counts)
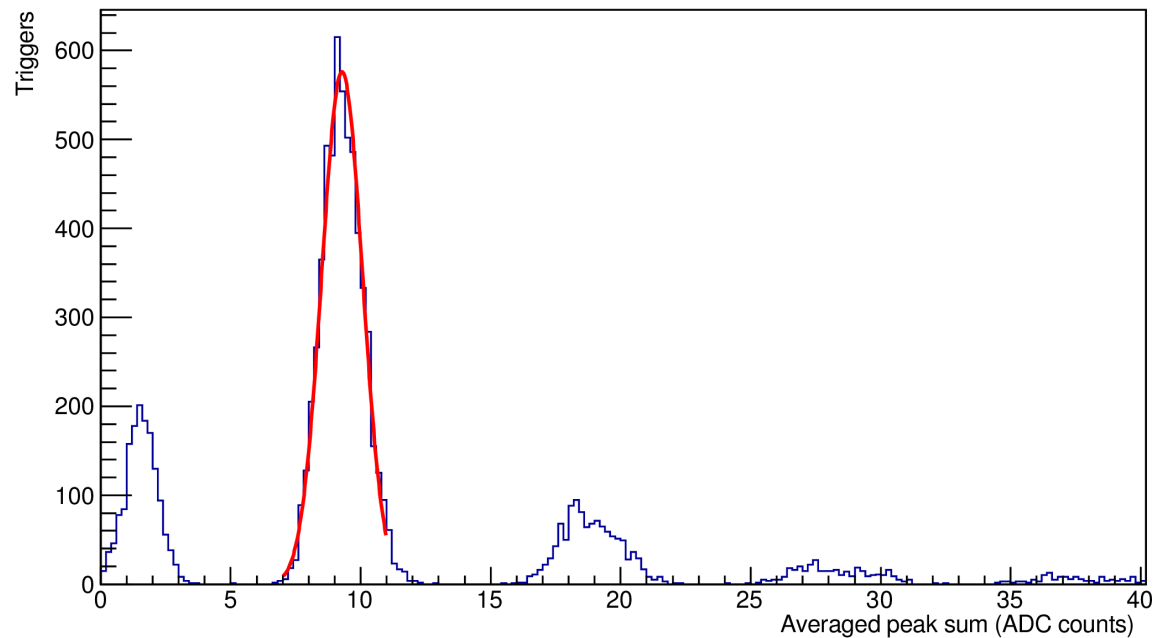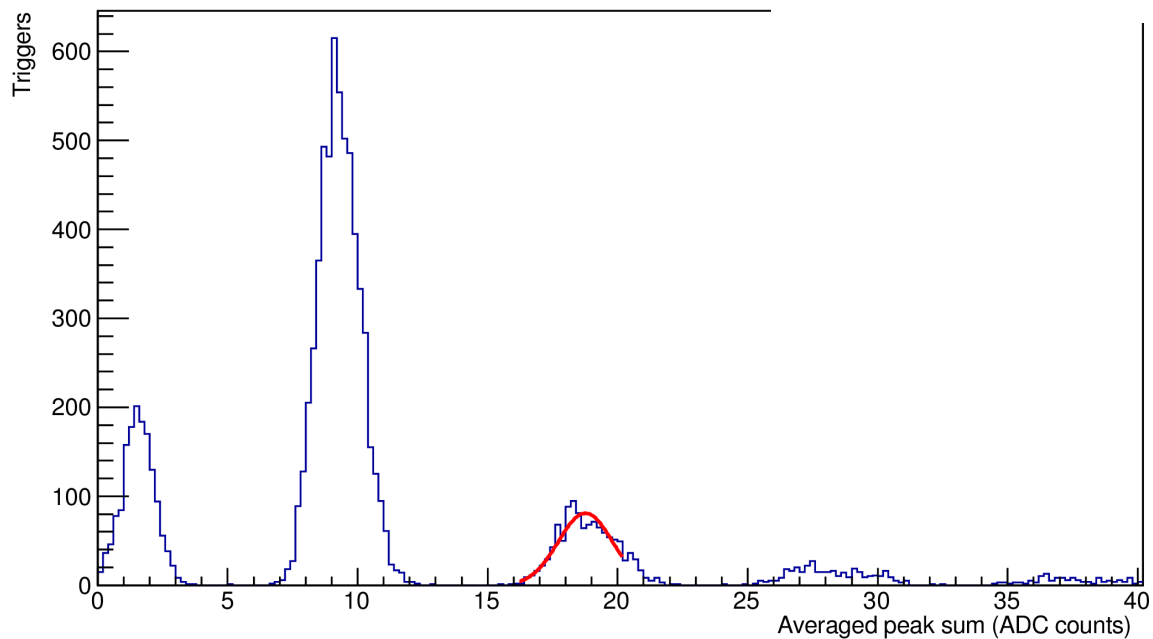
Gang of 3 SiPMs – 10m cable

Averaged 1 PE waveform

1 PE
selection

Averaged 2 PE wavefo

2 PE
selection

Gang of 6 SiPMs – 10m cable

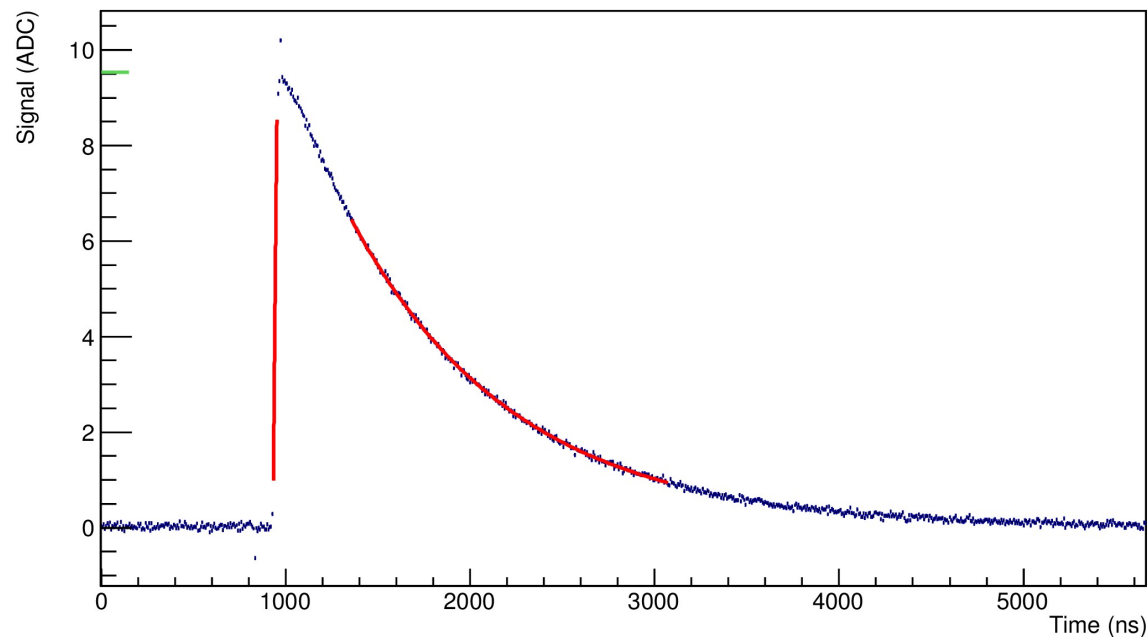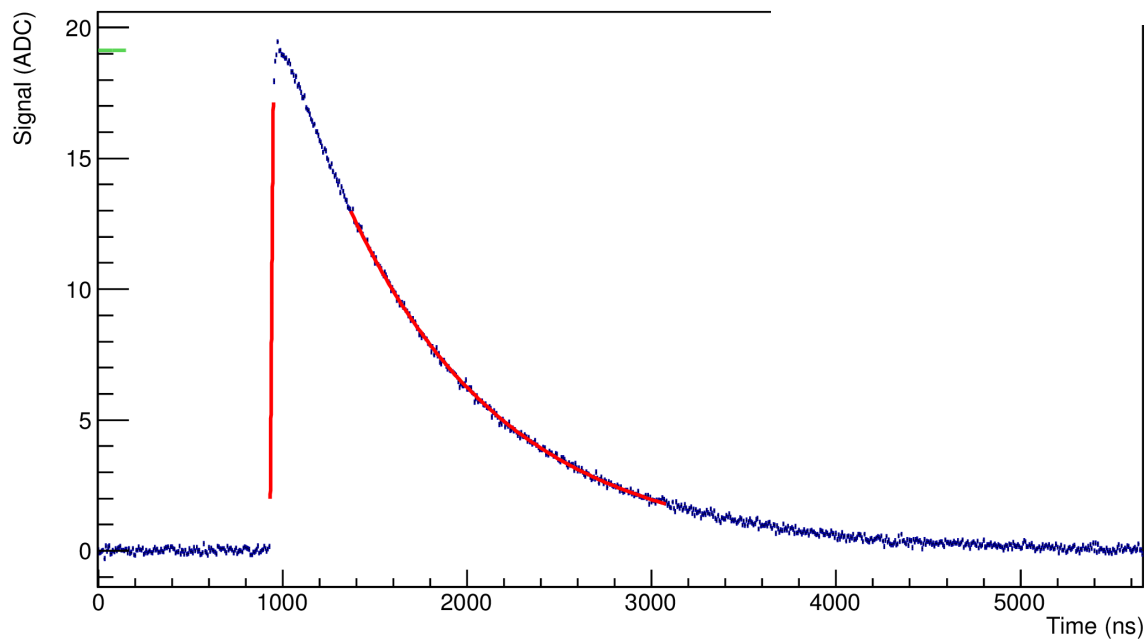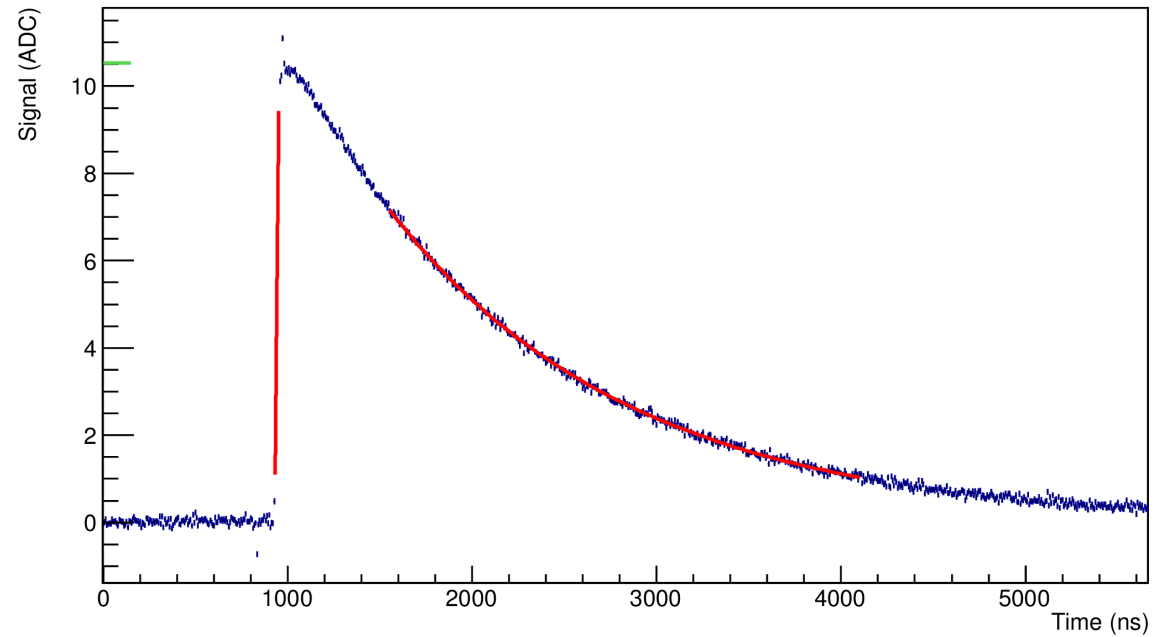Averaged 2 PE waveform

2 PE
selection

Signal peak distribution
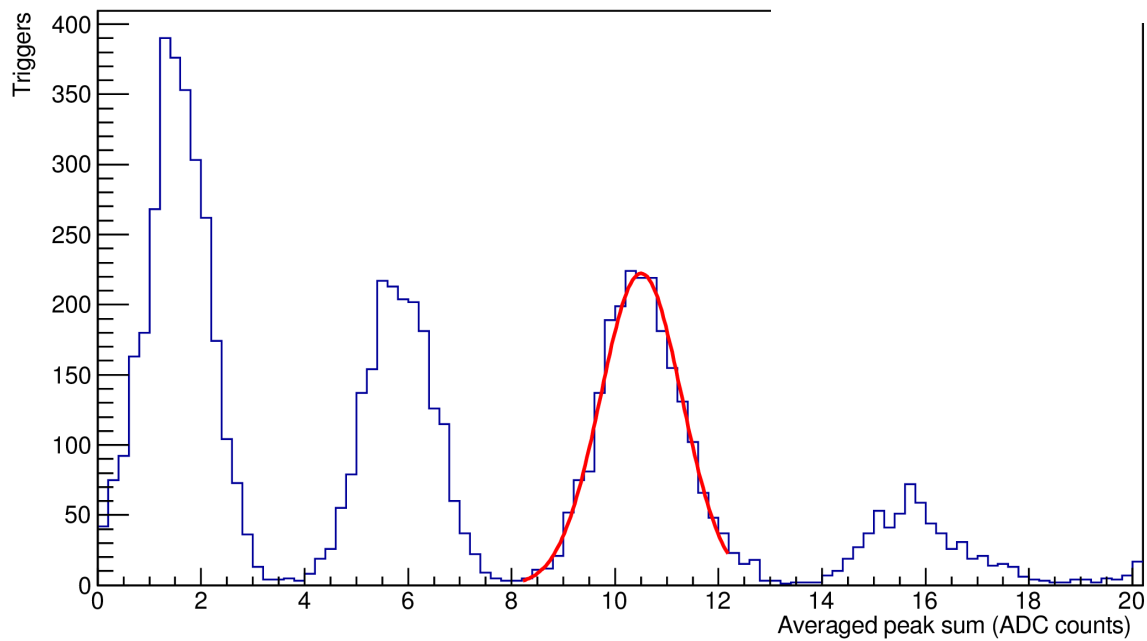
Signals at 10 m						
SiPM	ADC/PE	1 PE		2 PE		
		Rise Time (ns)	Decay Const. (ns)	Rise Time (ns)	Decay Const. (ns)	Baseline RMS (ADC)
Average Individual	20.3	13.4 +/- .3	473	12.8 +/- .4	468	2.45 +/- .18
Gang of 3	9.5	19.0 +/- .6	892	16.2 +/- .6	863	2.51 +/- .18
Gang of 6	5.3	--	--	19.9 +/- 1.0	1317	2.53 +/- .18

Gang of 3 SiPMs – 20m cable

Signal peak distribution

1 PE
selection

Signal peak distribution

2 PE
selection

21

Gang of 3 SiPMs – 20m cable

Averaged 1 PE waveform

1 PE
selection

Averaged 2 PE wavefo

2 PE
selection

22

Gang of 6 SiPMs – 20m cable
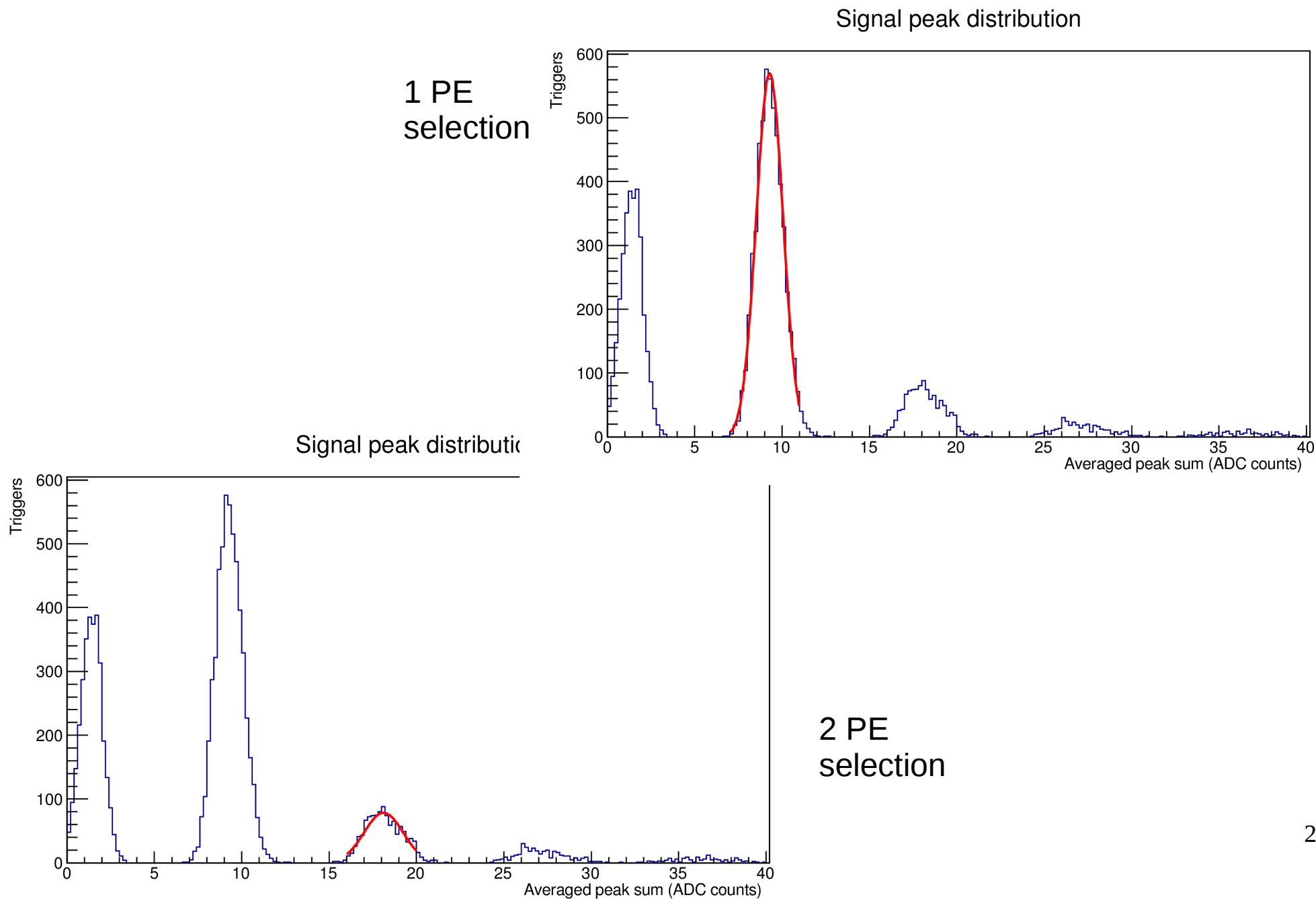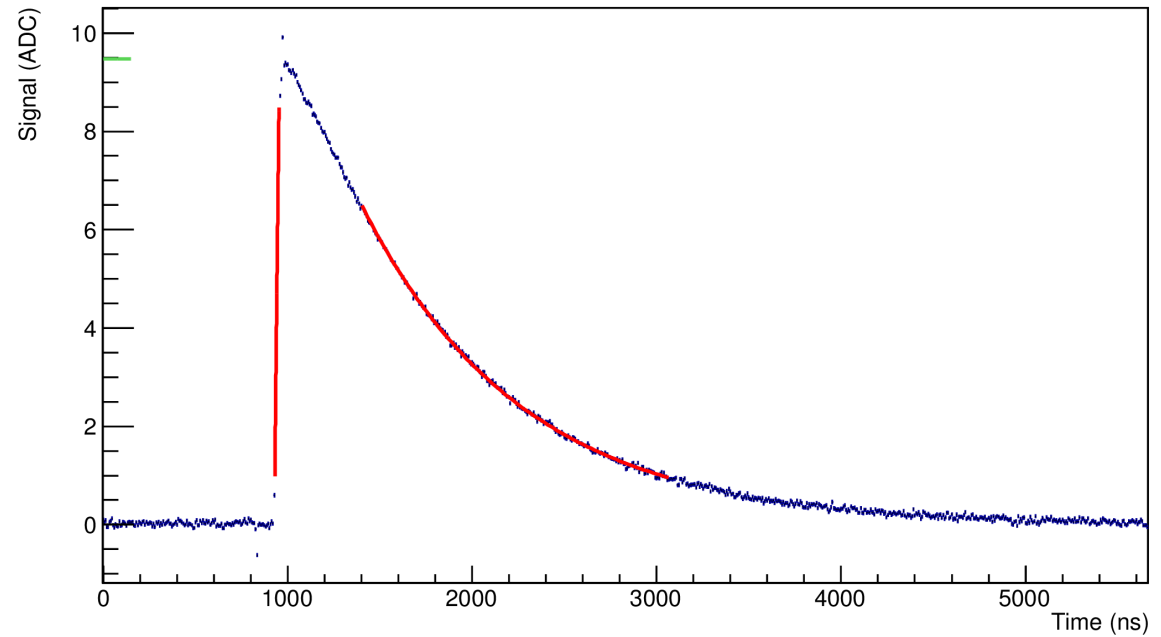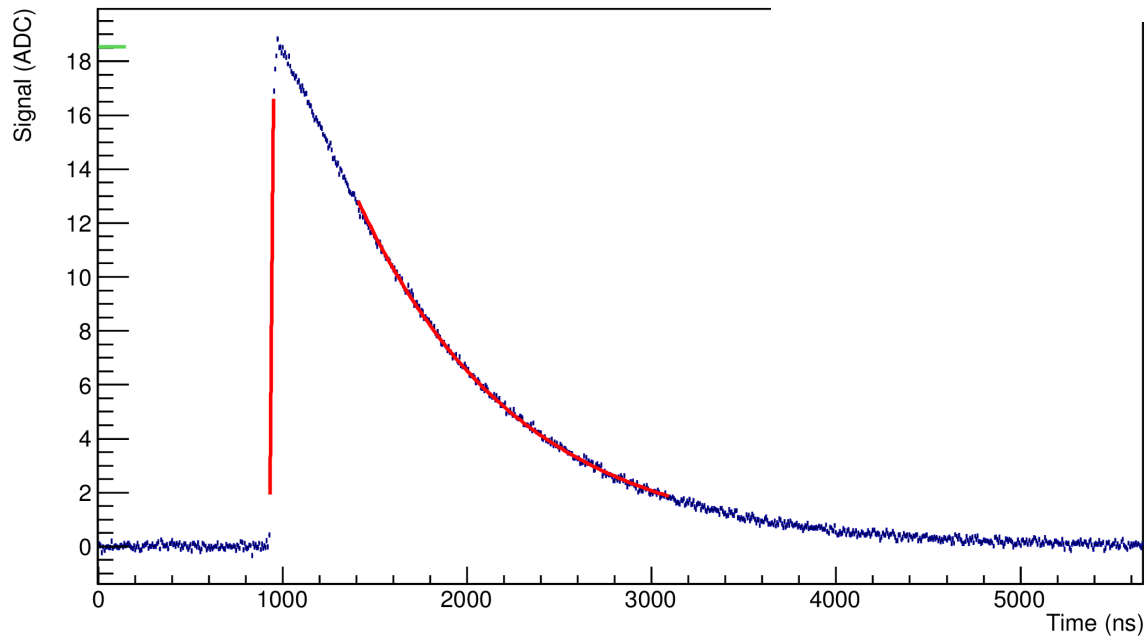
Averaged 2 PE waveform

2 PE
selection

Signal peak distributi...

23
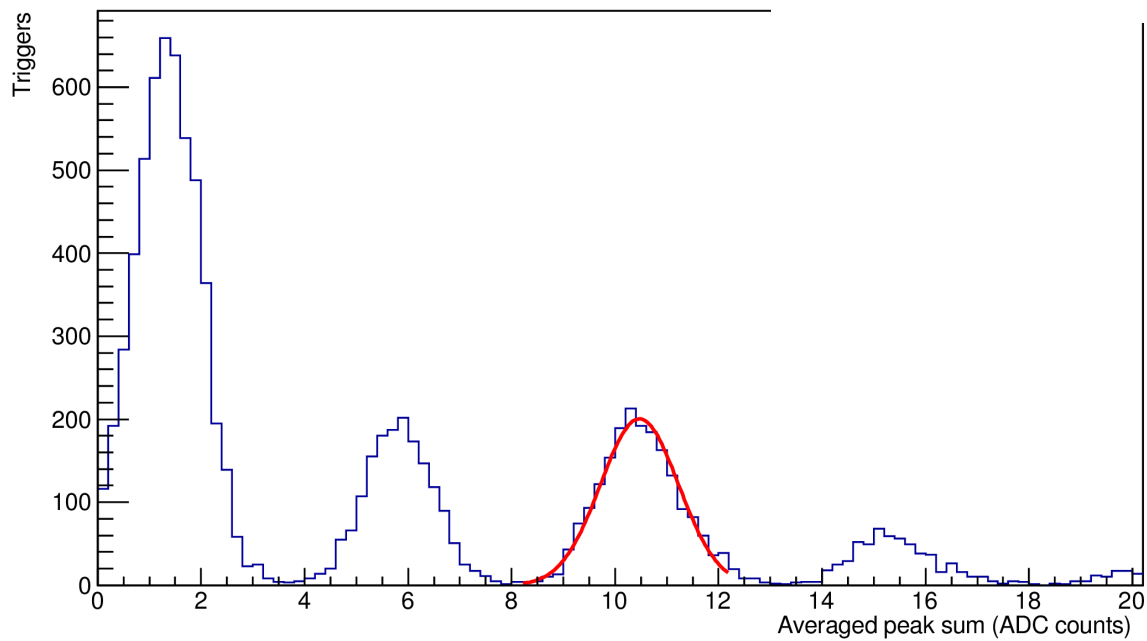
		Signals at 20 m				
SiPM	**ADC/PE**	**1 PE**		**2 PE**		
		Rise Time (ns)	**Decay Const. (ns)**	**Rise Time (ns)**	**Decay Const. (ns)**	**Baseline RMS (ADC)**
Average Individual	19.5	14.7 +/- .4	479	14.8 +/- .6	483	2.50 +/- .20
Gang of 3	9.4	22.9 +/- .9	868	18.9 +/- .8	874	2.50 +/- .19
Gang of 6	5.2	--	--	23.4 +/- 1.4	1282	2.55 +/- .20

Gang of 3 SiPMs – 40m cable

Signal peak distribution

1 PE selection

Signal peak distribution

2 PE selection

25

Gang of 3 SiPMs – 40m cable
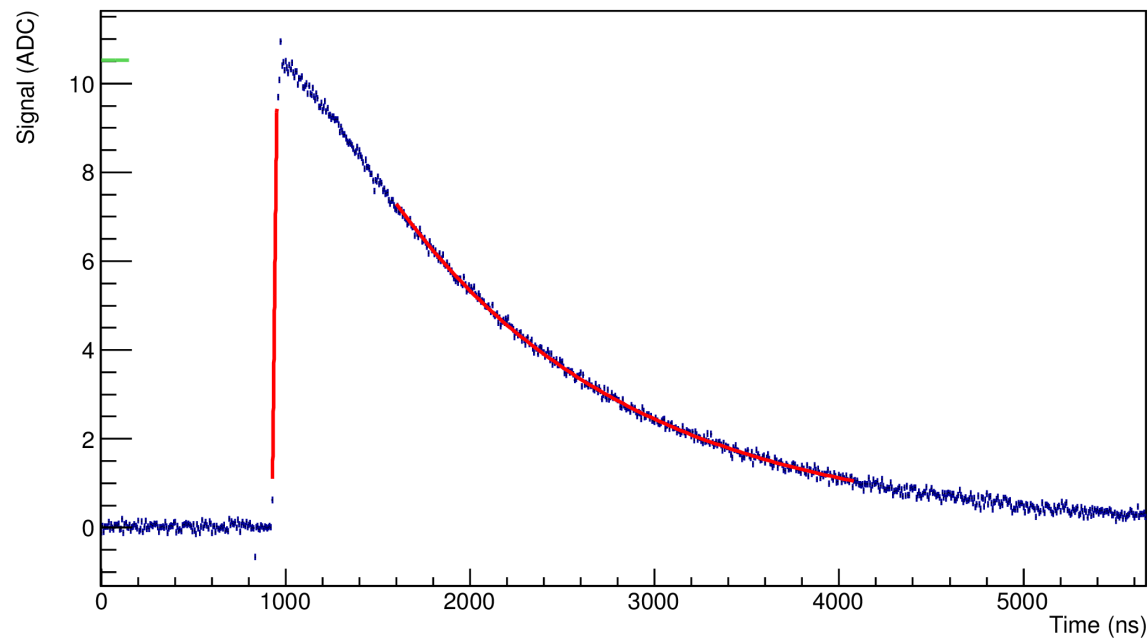
Averaged 1 PE waveform

1 PE
selection

Averaged 2 PE wavefo

2 PE
selection

Gang of 6 SiPMs – 40m cable

Averaged 2PE Waveform

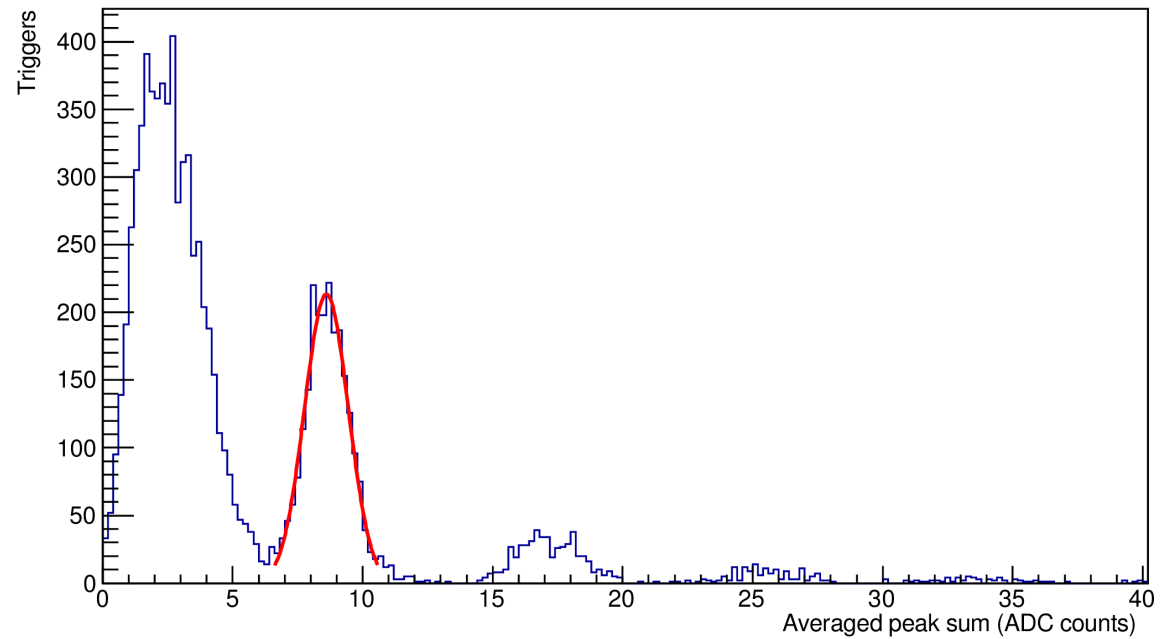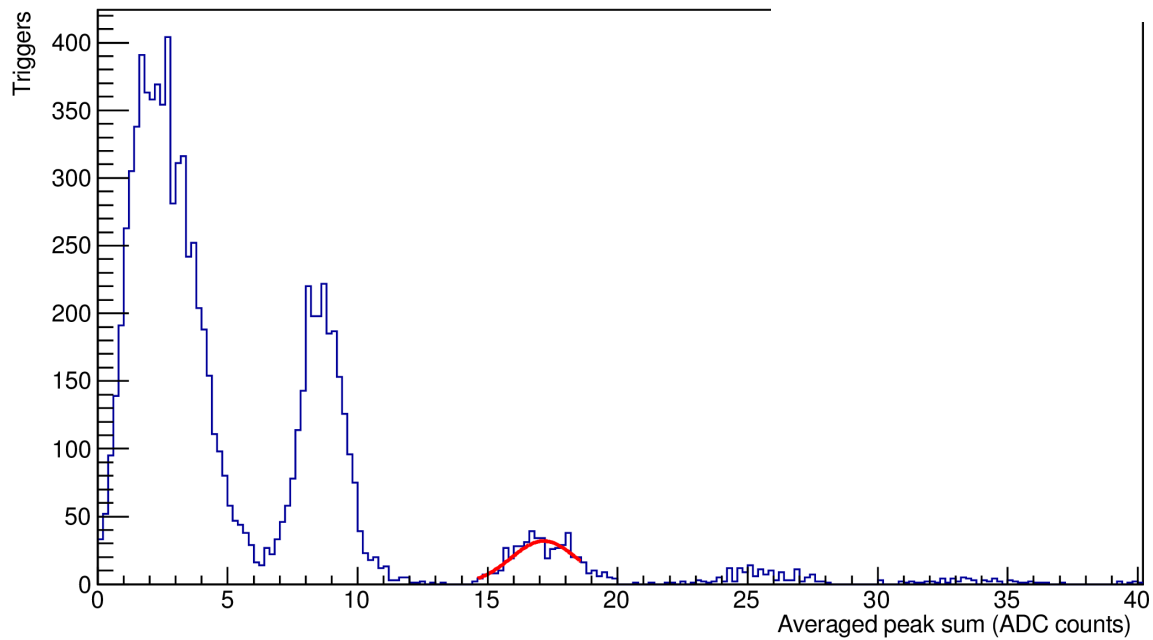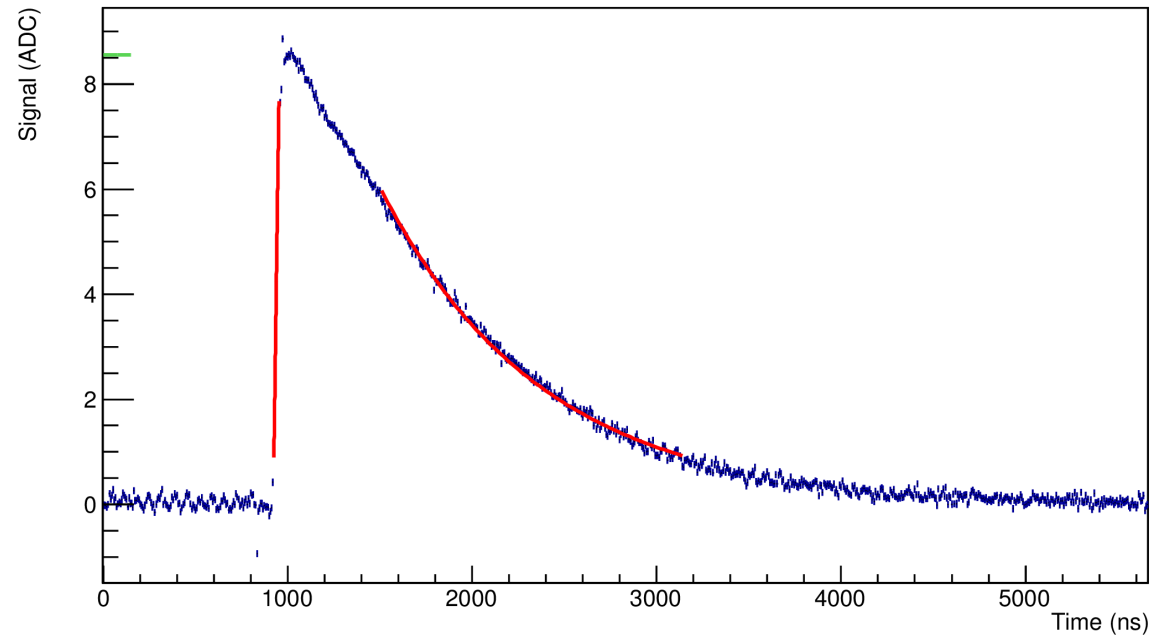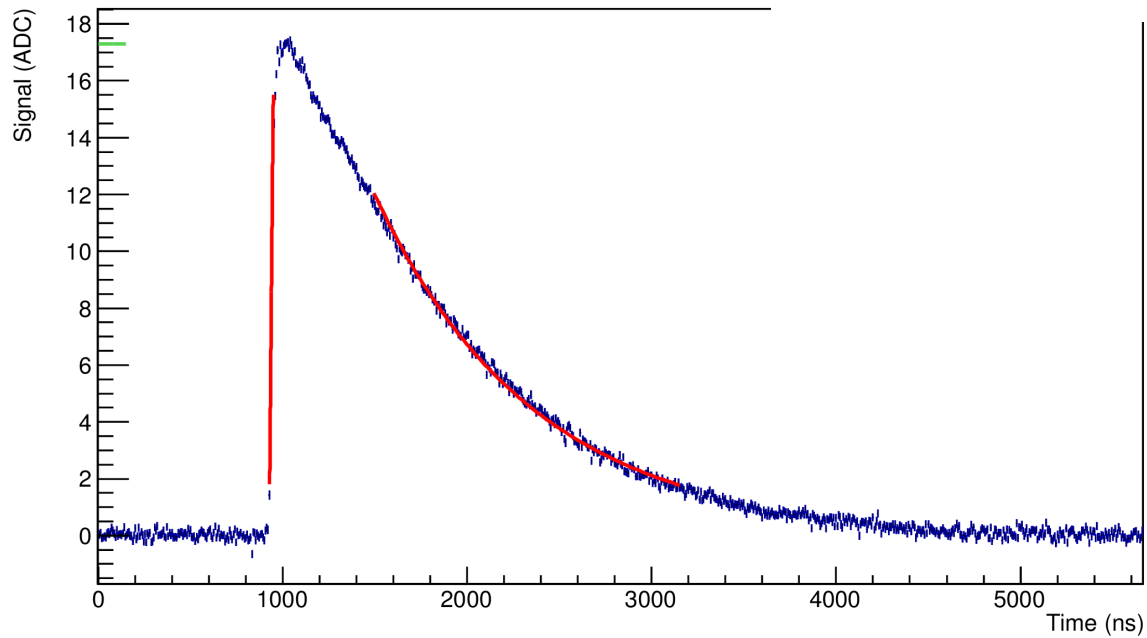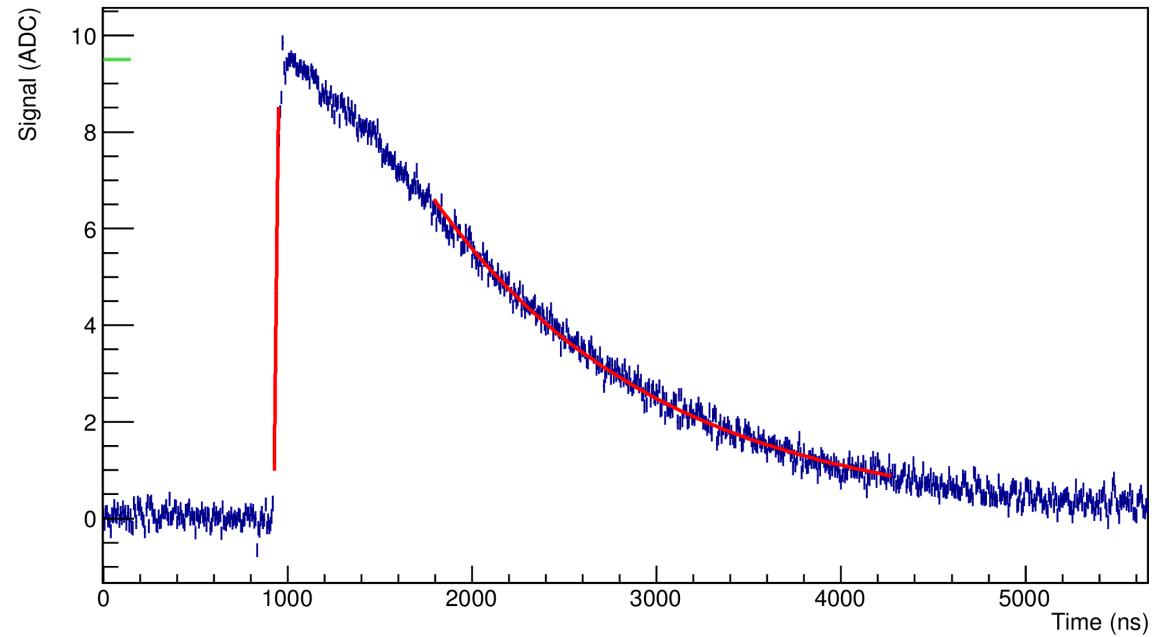## 2 PE selection

Signal peak distribution
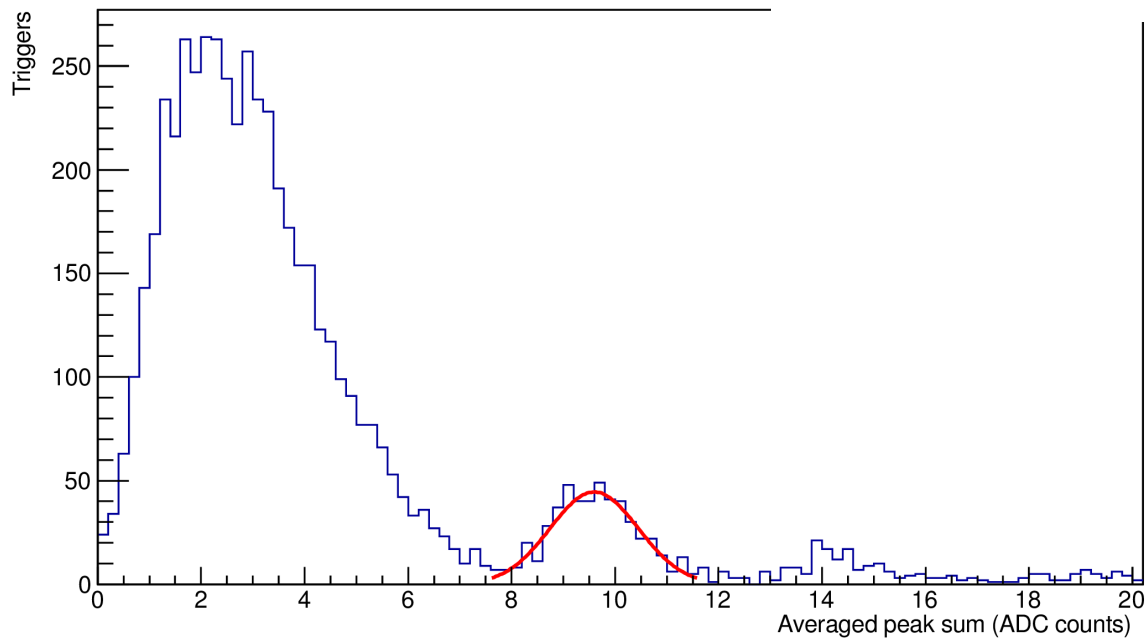
		Signals at 40 m				
SiPM	**ADC/PE**	**1 PE**		**2 PE**		
		Rise Time (ns)	**Decay Const. (ns)**	**Rise Time (ns)**	**Decay Const. (ns)**	**Baseline RMS (ADC)**
Average Individual	17.8	18.6 +/- .7	490	14.7 +/- .5	482	2.55 +/- .22
Gang of 3	8.6	27.1 +/- 2.1	877	20.3 +/- 1.4	866	2.63 +/- .29
Gang of 6	4.8	--	--	23.5 +/- 3.1	1233	2.67 +/- .29

| Gang of 3 Summary						
Cable Length (m)	ADC/PE	1 PE		2 PE		
		Rise Time (ns)	Decay Const. (ns)	Rise Time (ns)	Decay Const. (ns)	Baseline RMS (ADC)
10	9.5	19.0 +/- .6	892	16.2 +/- .6	863	2.51 +/- .18
20	9.4	22.9 +/- .9	868	18.9 +/- .8	874	2.50 +/- .19
40	8.6	27.1 +/- 2.1	877	20.3 +/- 1.4	866	2.63 +/- .29

Passive Ganging Results

- Some 40m cables seemed much noisier than this cable. We are unsure of the source/nature of this noise.
  - Can try to further characterize this in future work
  - When taking data without this large amount of noise, triggering on individual SiPMs works even at 7 ADC (less than half a PE)
- For the gang of 3, a 7 ADC trigger also works, but is more than half a PE
  - With an RMS of ~2.5-2.6 ADC it is expected that noise will begin to dominate at lower threshold values.
  - This was tested in the 10m cable for passive gang of 3 SiPMs (see next slide)
- Even at 10m, the ADC/PE is too close to the RMS to effectively trigger on 1PE for gang of 6. A 2PE trigger seems fine.

Passive Ganging Results

Triggers collected over 3 minutes with a different leading edge discriminator threshold
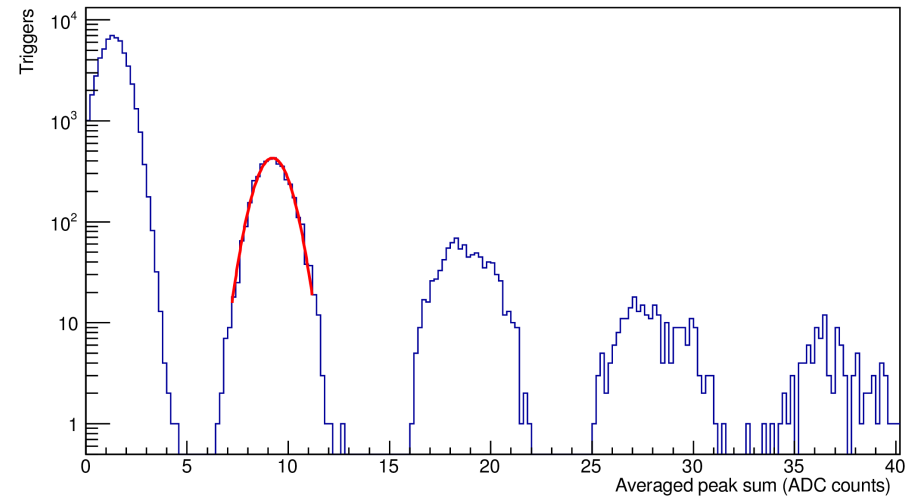
Trigger of 5ADC (log-y plot)
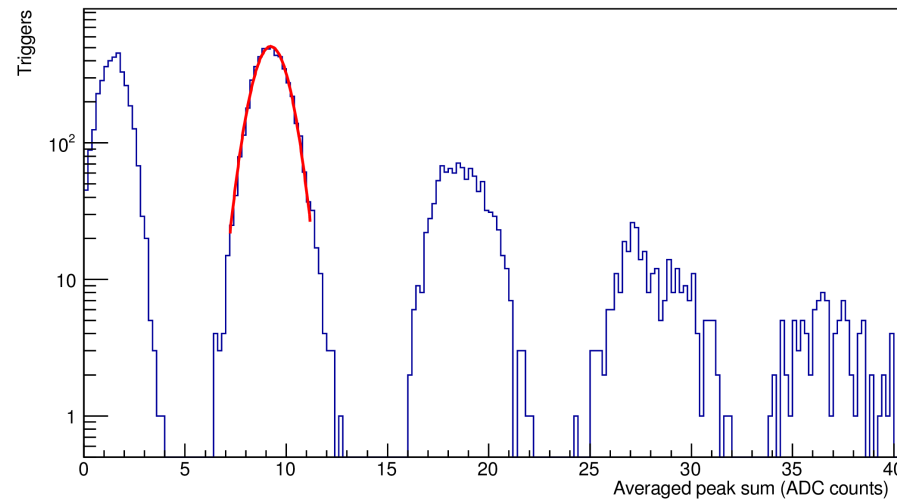

Signal peak distribution
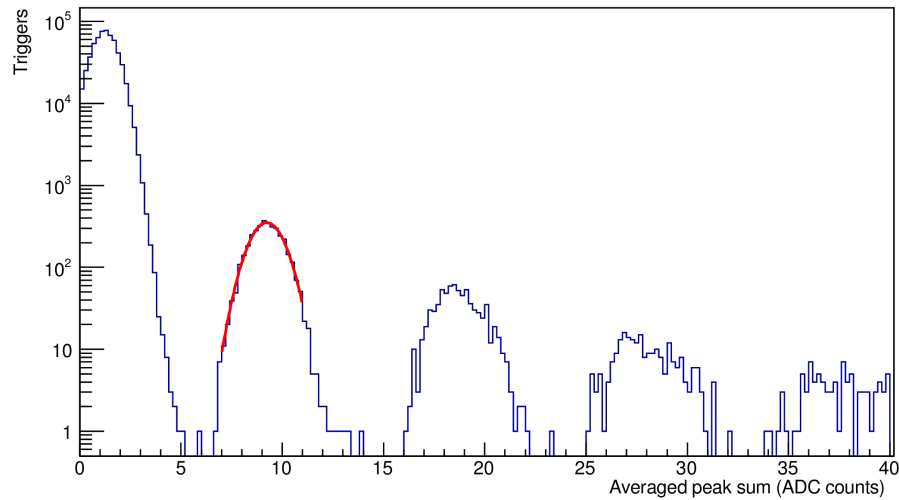
Trigger of 6ADC (log-y plot)

Signal peak distribution

Signal peak distribution
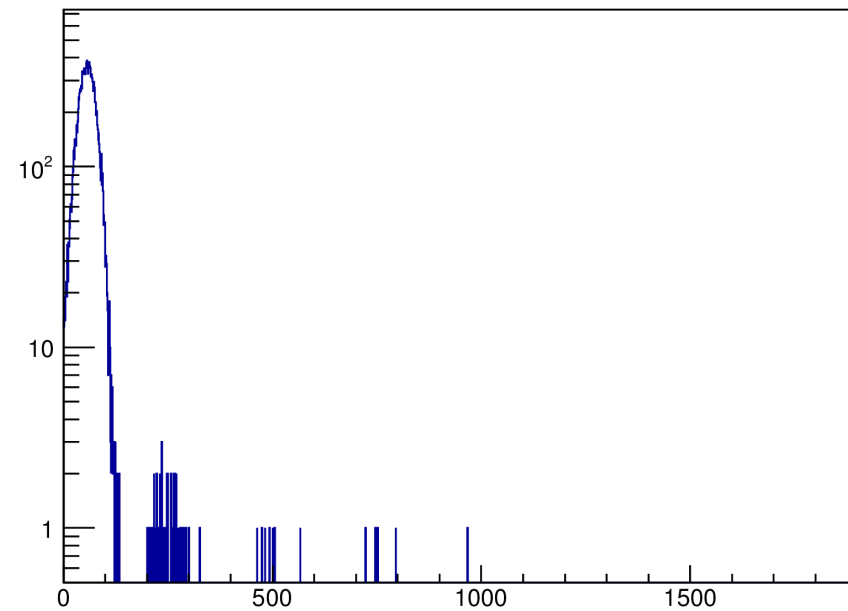
Trigger of 7ADC
(log-y plot)

31

Active Ganging Results

- Active board contains two gangs of 3 SiPMs connected by summing amplifiers and a gang of 6 SiPMs connected by summing amplifiers

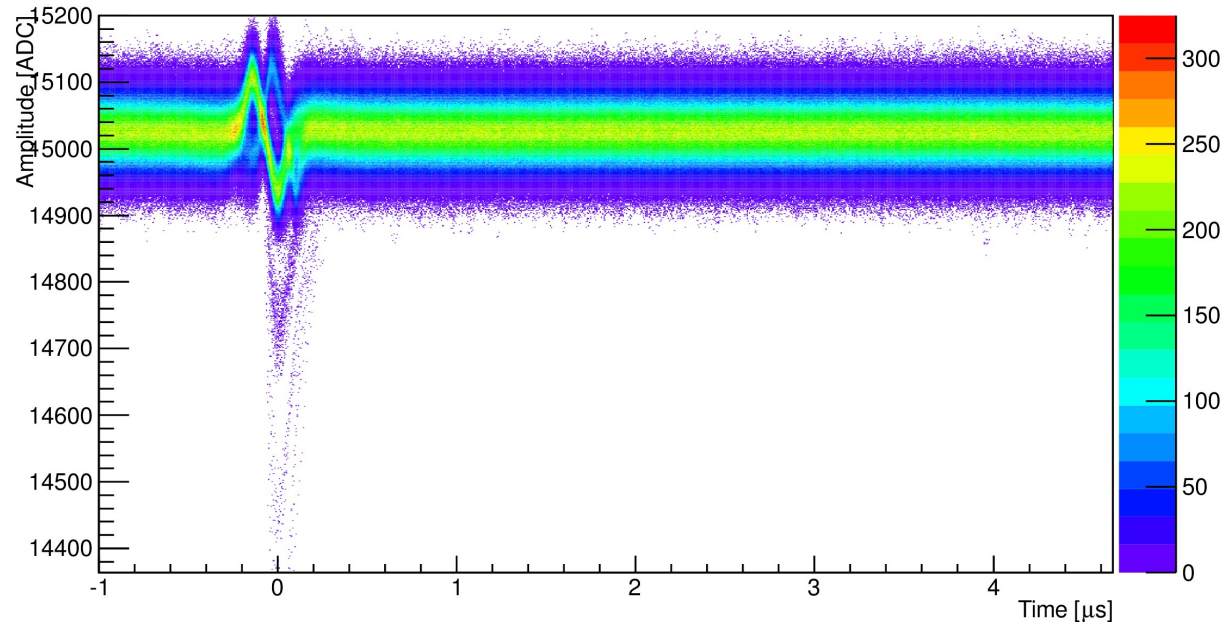- Current iteration of the board has some issues that might be remedied with future changes

Gang of 3

Gang of 3

Gang of 6

Extra cables for controlling the bias settings via SPI terminal.
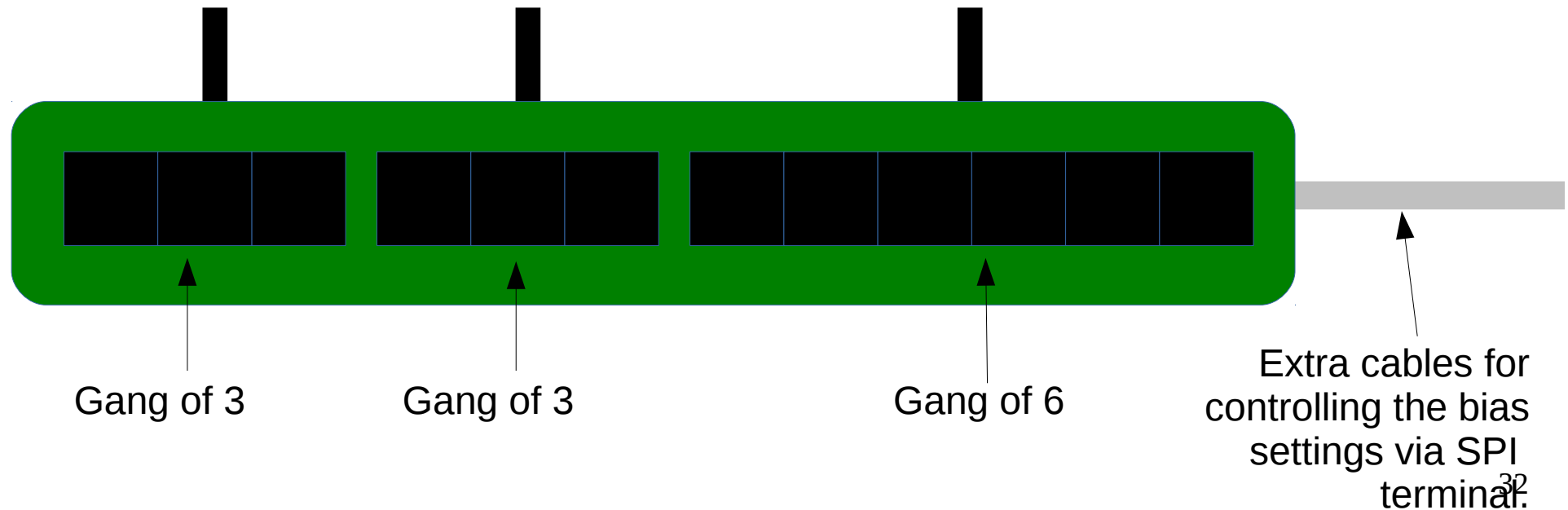
Active Ganging Results

Pulse Amplitudes, SSP Channel 18-8

All Waveforms, Channel 18-8

- High rate of 0 PE "bursts" (possibly from on-board amplifiers?)
- Still separation between 0 and 1 PE, so we report a first look at what signals look like (work in progress)
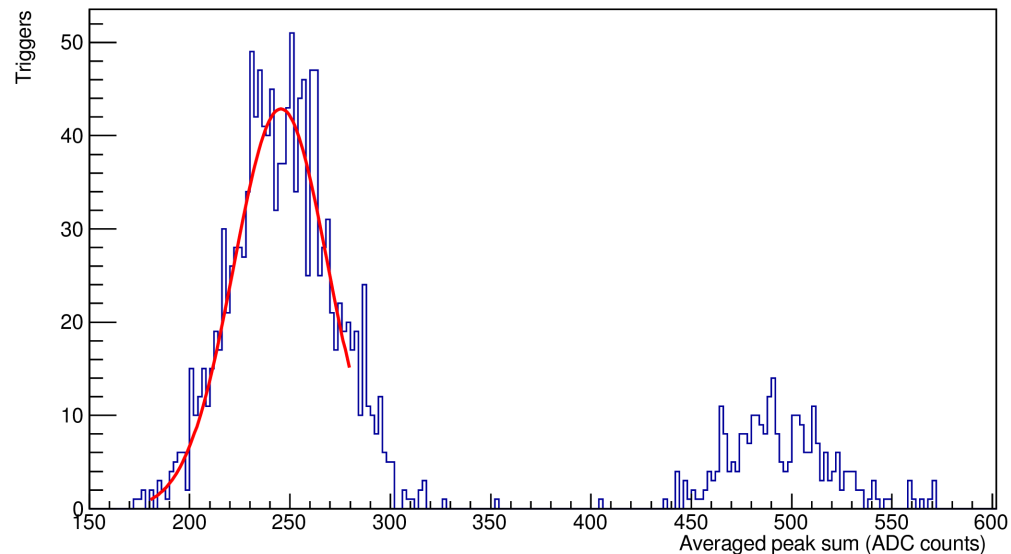
Active Ganging Results

- One way of getting around this for the time being is to use the peakSum variable as rejection during data-taking

  – An event passing the leading edge discriminator in SSP is only recorded if

  $$(peakSum/samples\ summed) > threshold-2$$

  where threshold is the user-set leading edge threshold.

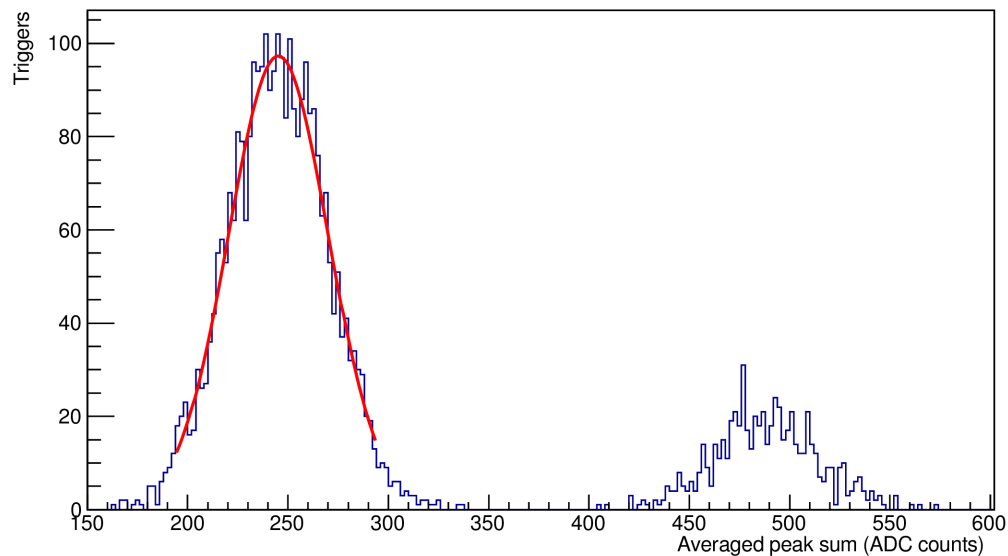- This allows us to collect mostly the desired signal without amassing lots of these 0PE bursts

Active Ganging Results

Signal peak distribution

Single SiPM
in gang of 3
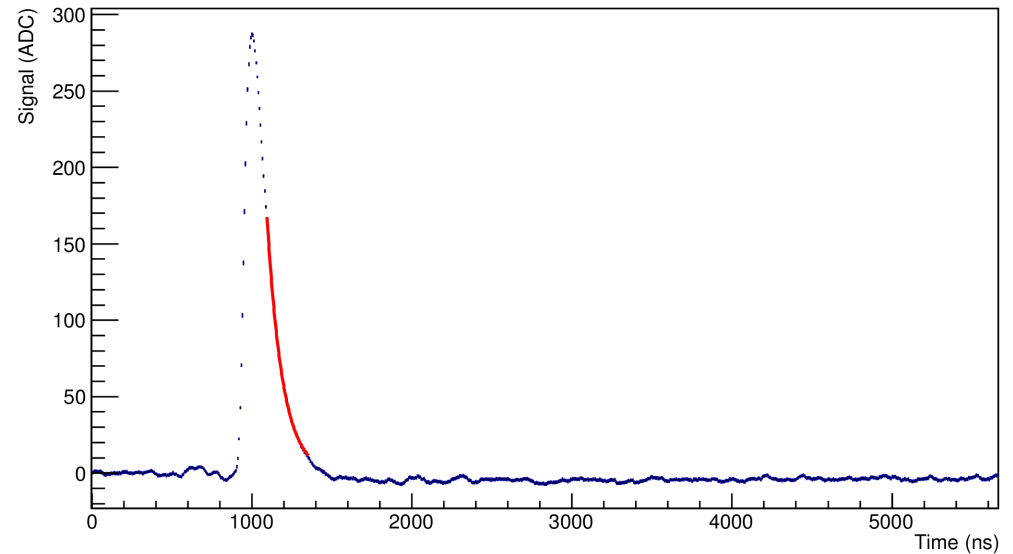
All SiPMs
in gang of 3

35

Active Ganging Results

Single SiPM
in gang of 3

Averaged 1PE Waveform

All SiPMs
in gang of 3
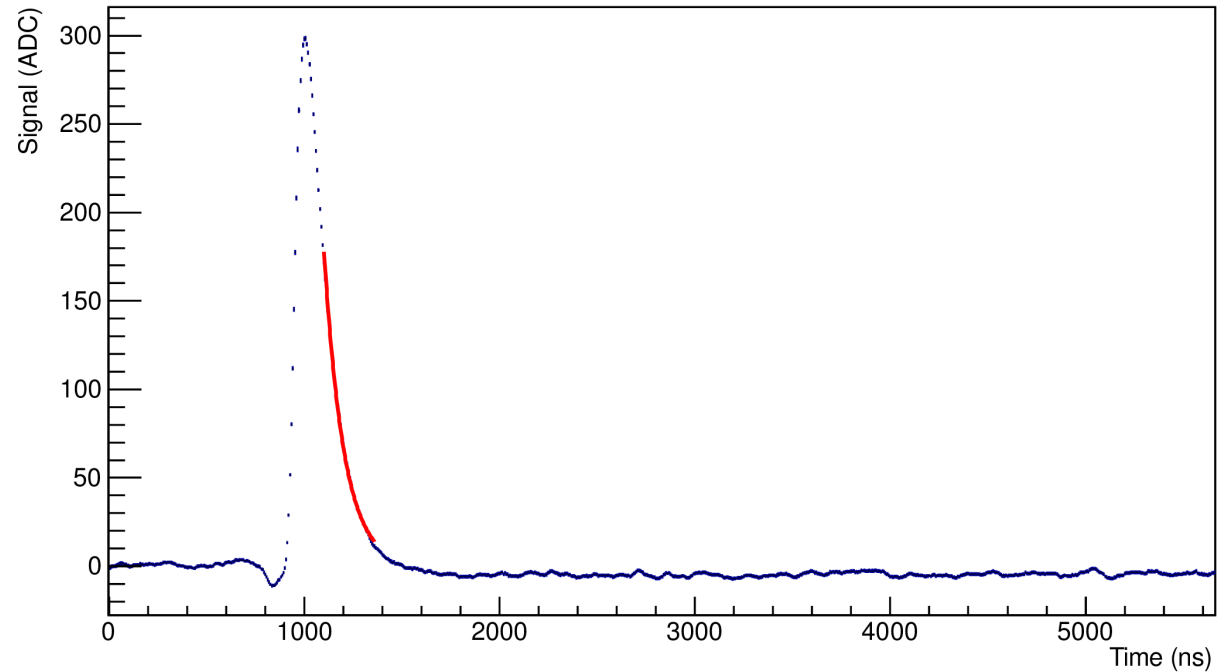
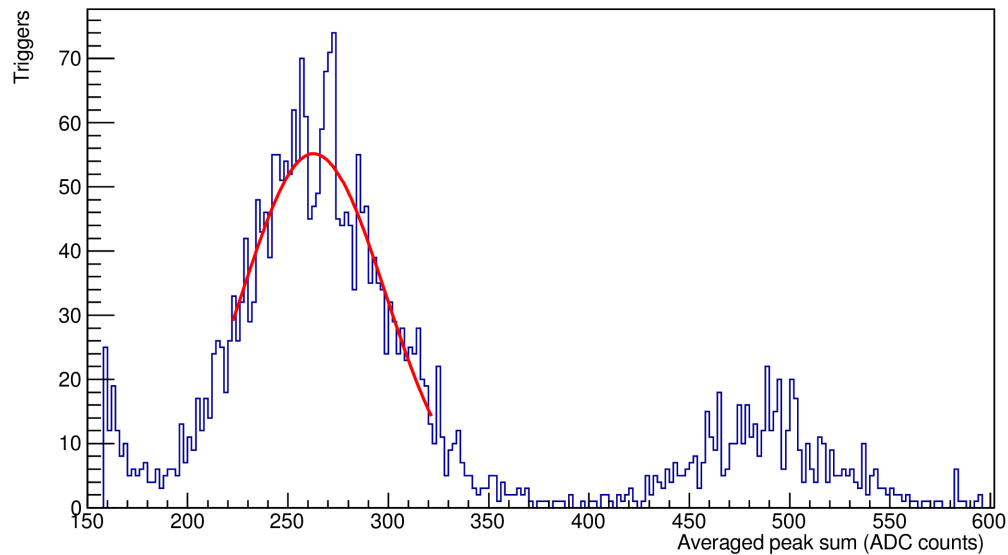Averaged 1PE Waveform

36
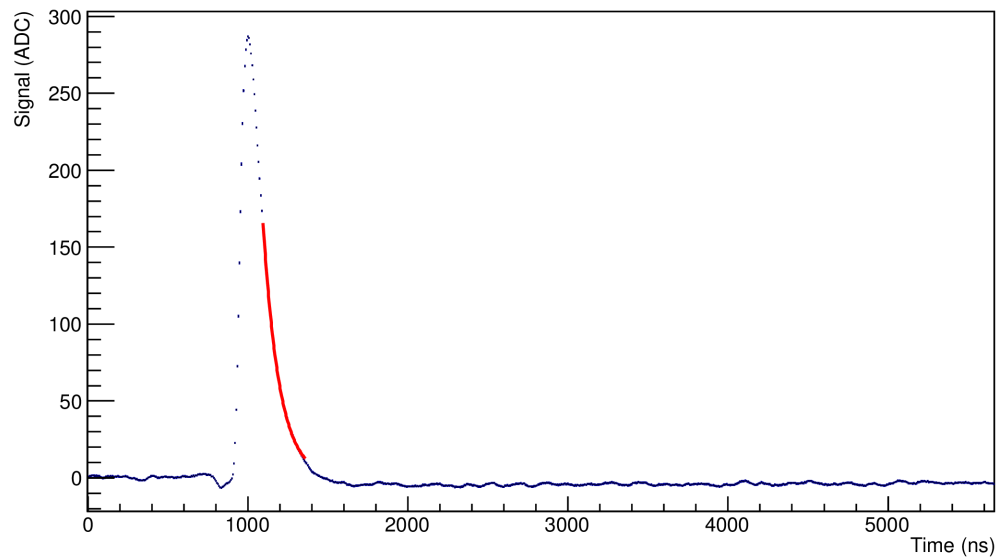
Active Ganging Results

Averaged 1 PE waveform

Single SiPM in gang of 6

Signal peak distribution

Active Ganging Results

SiPM set	1 PE peak (ADC) (avg waveform)	1 PE rise time (ns)	1 PE decay constant (ns)
Single SiPM in gang of 3	284.1	45.3	96.5
Entire gang of 3	283.6	45.3	102
Single SiPM in gang of 6	295.3	49.2	101

- Can operate any combination SiPMs in each gang above breakdown voltage
- Pick bias voltages to match gain
  - This gives clear separation of PE peaks within a gang
  - Each SiPM should then behave the same as the gang
- Though different characteristics from passive SiPMs, SiPMs in different gangs look similar
  - Single SiPM in gang of 6 looks basically the same as gang of 3 (and single SiPM in that gang of 3)
- If work out issues with current board, there is hope to potentially trigger on 1PE in a gang of 6

Conclusions

- Passive ganging
  - Works well for 3 SiPMs (albeit with > ½ PE trigger)
  - Gang of 6 SiPMs seems fine, but cannot trigger on 1PE
  - Effects of noise in 40m cable are under investigation
- Active ganging
  - Ganging proof of principle
    - Different signal characteristics
    - Might be able to see 1 PE for a gang of 6 SiPMs
  - Work in progress
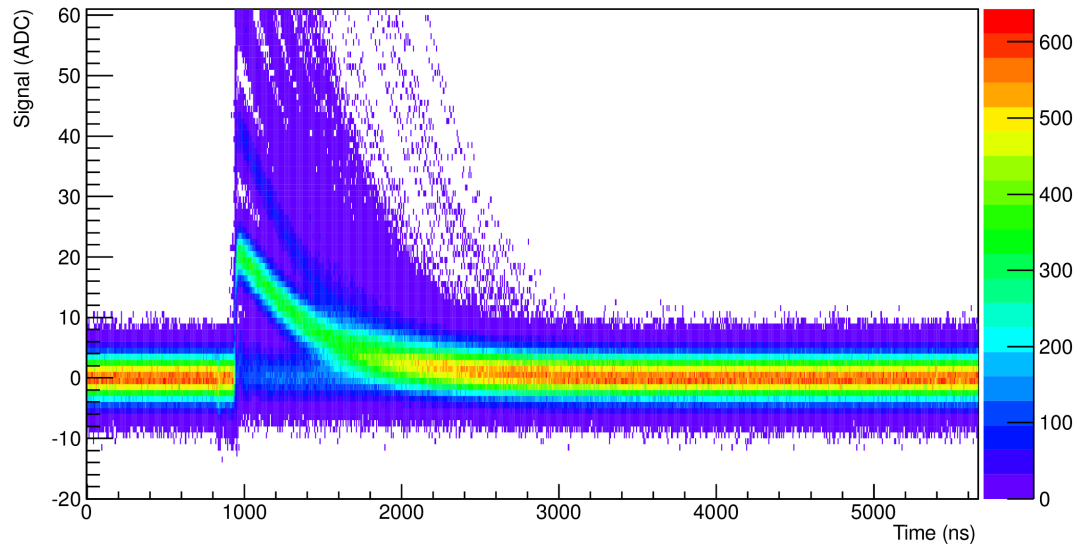   - Issues to work out, such as "burst" noise from board

Backups

Persistence traces

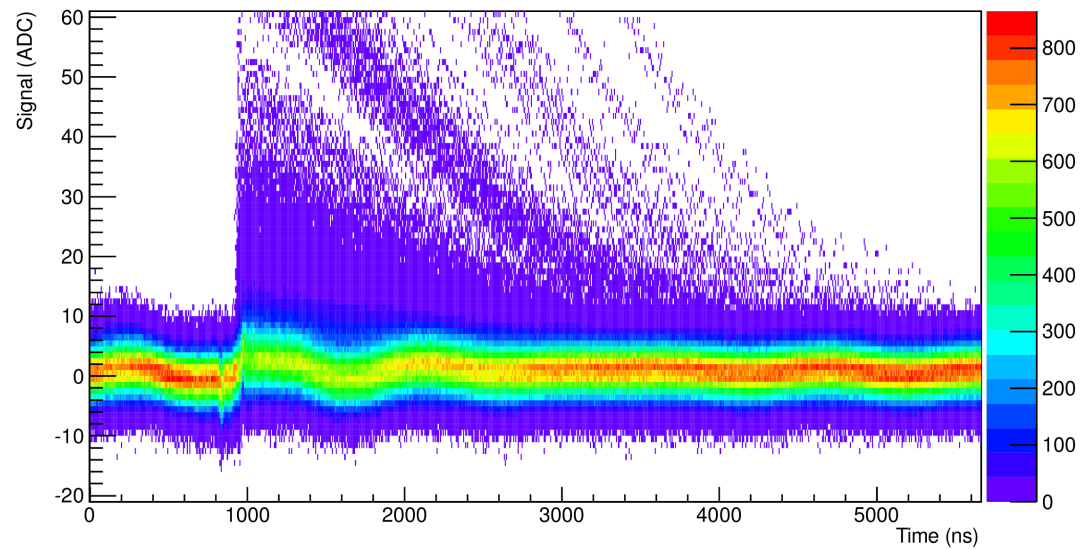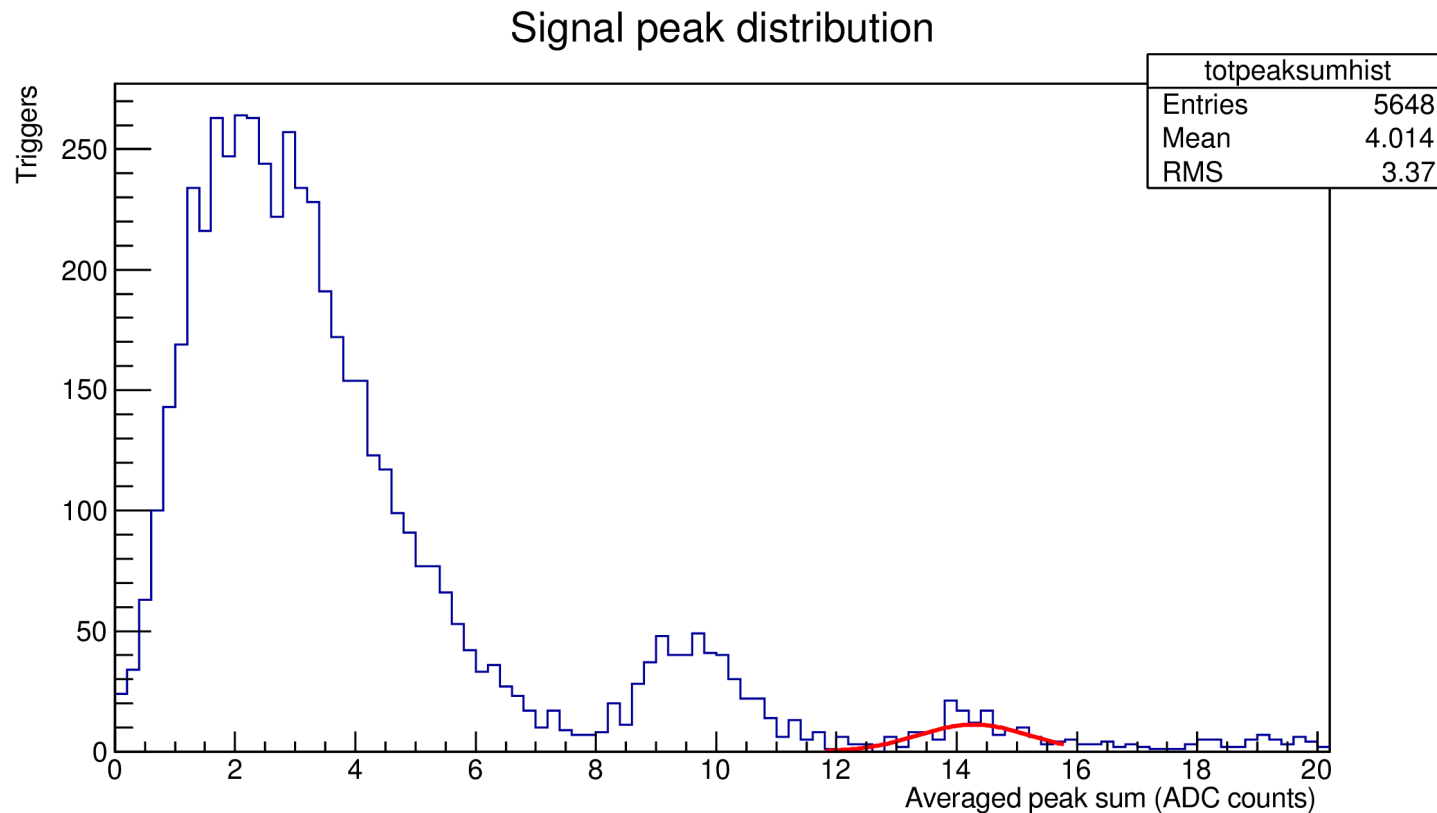## One SiPM – 10m cable

All waveforms stacked

Gang of 6 SiPM – 40m cable

All waveforms stacked

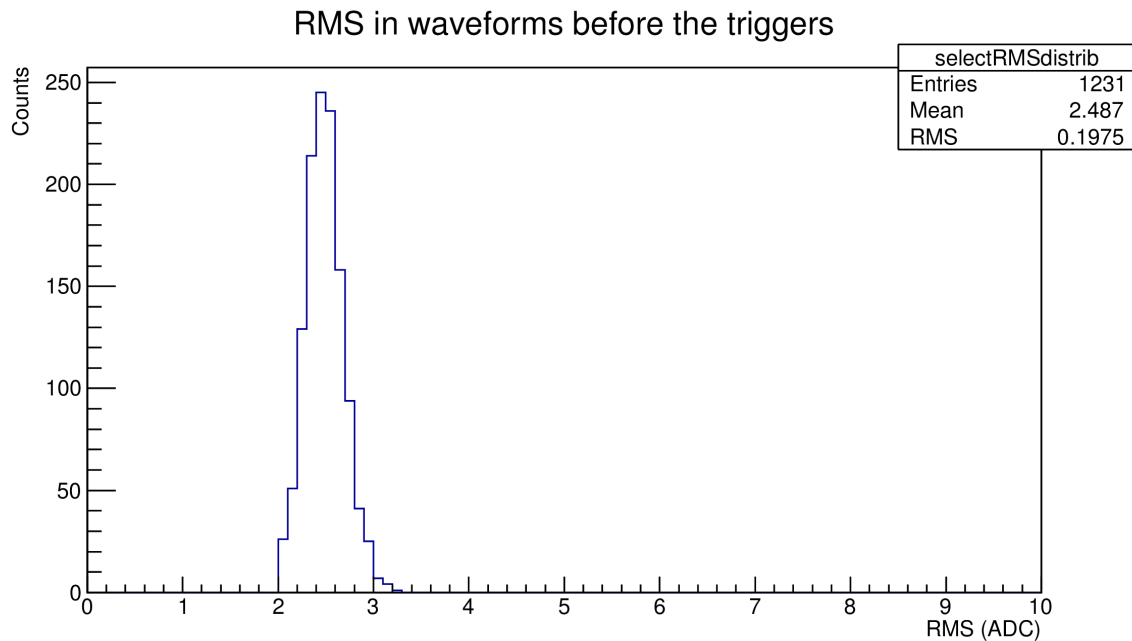# 3 PE selection for gang of 6 at 40m (used in finding ADC/PE)

Selection RMS histograms

RMS in waveforms before the triggers

A single SiPM
1 PE, 10m

selectRMSdistrib	
Entries	1410
Mean	2.451
RMS	0.1741

RMS in waveforms before the triggers

selectRMSdistrib	
Entries	1231
Mean	2.487
RMS	0.1975

A single SiPM
1 PE, 20m

43

Selection RMS histograms

RMS in waveforms before the triggers

selectRMSdistrib	
Entries	1020
Mean	2.535
RMS	0.2174

A single SiPM
1 PE, 40m

RMS in waveforms before the triggers

selectRMSdistrib	
Entries	729
Mean	2.505
RMS	0.1803

Gang of 3 SiPMs
2 PE, 10m

44

Selection RMS histograms

RMS in waveforms before the triggers

Gang of 3 SiPMs
2 PE, 20m

selectRMSdistrib	
Entries	763
Mean	2.504
RMS	0.1886

RMS in waveforms before the triggers

selectRMSdistrib	
Entries	366
Mean	2.631
RMS	0.2877

Gang of 3 SiPMs
2 PE, 40m

45

Selection RMS histograms

RMS in waveforms before the triggers

selectRMSdistrib	
Entries	1508
Mean	2.529
RMS	0.1814

Gang of 6 SiPMs
2 PE, 10m

RMS in waveforms before the triggers

selectRMSdistrib	
Entries	1292
Mean	2.551
RMS	0.2036

Gang of 6 SiPMs
2 PE, 20m

46

Selection RMS histograms

Gang of 6 SiPMs
2 PE, 40m

RMS in waveforms before the triggers

selectRMSdistrib	
Entries	338
Mean	2.667
RMS	0.2866